Urban Roads and the Endangered San Joaquin Kit Fox

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16. ABSTRACT

The San Joaquin kit fox (*Vulpes macrotis mutica*) is at risk of extinction primarily due to profound habitat degradation, fragmentation, and loss. However, kit foxes inhabit some urban areas, and roads present a potential threat to kit foxes in these areas. From 1998-2004, we investigated the effects of roads on urban kit foxes in Bakersfield, California. Vehicles were the primary cause of mortality for urban kit foxes, and most strikes occurred on arterial roads, which had higher traffic volumes and speed limits. Also, foxes were more frequently struck near intersections between major roads and other linear rights-of-way (e.g., railroads, canals, other roads), which likely were used as travel corridors by kit foxes. Males appeared to be particularly vulnerable to vehicle strikes during the winter mating season. Kit foxes did not appear to avoid roads when selecting den sites. During nocturnal activity periods, kit foxes commonly crossed local roads, but less frequently crossed arterial or collector roads. Roads impact urban kit foxes through reduced survival, occasional den loss, inhibited movements, and habitat loss. When conducting road projects (e.g., construction, maintenance), Caltrans implements standard measures to minimize impacts to kit foxes. We recommend the implementation of additional measures, specifically the installation of artificial dens and road crossing structures, to further minimize impacts. Implementation of these measures will facilitate conservation of urban kit foxes and contribute to range-wide recovery.

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DISCLOSURE

This research was done under contract 65A0136. The contract total was $170,700.

DISCLAIMER

EXECUTIVE SUMMARY

The San Joaquin kit fox (*Vulpes macrotis mutica*) is at risk of extinction primarily due to profound habitat degradation, fragmentation, and loss. Industrial and urban developments are contributing factors to habitat destruction. Based on recent research, however, kit foxes appear to have persistent populations in some urban and industrial lands. While many factors regulate urban fox populations, roads are a dominant feature of these areas, and a potential threat to kit fox populations. Roads may affect fox survival, den use, movements, and other essential functions. Furthermore, the potential for negative impact is proportional to road width, traffic volume, and speed limit. Projections for the San Joaquin Valley indicate that the human population and associated urbanization and transportation networks will increase for the foreseeable future. Roads will grow wider, carry higher traffic volumes, and become more inhospitable to wildlife. As urban lands spread and natural lands diminish, urbanized fox populations also may become more valuable to species recovery. Consequently, the influence of transportation networks on the persistence of urban fox populations will grow simultaneously to the importance of those populations. Identifying ways to reduce the impact of urban roads on the kit fox is therefore important to species recovery.

The goal of this project was to examine effects of transportation networks (particularly roads) on urbanized San Joaquin kit foxes. Fox-vehicle collision was the primary cause of mortality for urban kit foxes and most strikes occurred on arterial roads that had relatively higher traffic volumes and posted speed limits. Fox-vehicle collision also showed temporal and spatial variability. Foxes more frequently were struck near intersections between major roads and other linear rights-of-way, including railroads, golf courses, canals, rivers, and other roads of all sizes. Furthermore, male kit foxes died disproportionately on roads during winter when mating, territory defense, and exploratory movements were common.

Kit foxes did not show preference for or avoidance of dens with respect to proximity to major roads (arterial, collector, highway, and highway ramp). A 100ft buffer (Fish and Wildlife Service exclusion zone) from the centerline of major roads included 9.5% of known kit fox dens at the study site. Proximity of dens (especially natal sites) to major roads, however, may increase risk of vehicle strike. Furthermore, earth moving associated with road construction and improvement may endanger kit foxes that inhabit roadside dens. Finaly, land that is converted to roadway is permanently lost as kit fox habitat. Therefore, while the selection of den sites by kit fox did not appear influenced by road proximity, there were several impacts of roads on the availability and suitability of habitat for dens.

We report on 21 sessions of vehicle-based intensive monitoring with 15 different focal kit foxes. In all, we recorded 4,633 minutes of observation over 44,121m of minimum straight line distance (MSLD) between consecutive points. Using MSLD and observation time, we calculated that foxes traveled at an average rate of 0.5958 km/hr during intensive monitoring. We directly observed foxes crossing local roads on 10 occasions and arterial and collector roads on one occasion, each. MSLD predicted that foxes made

108 road crossings during monitoring. The majority (79 crossings) occurred on local roads, while 12 and 17 crossings occurred on arterial and collector roads, respectively. Rate of road crossing per road type was in direct contrast to frequency of fox-vehicle collision per road type. Foxes most frequently crossed local roads, but most frequently died on arterial roads.

In addition to analyzing the effects of roads on kit foxes, we provide detailed recommendations on protection and compensation measures for urban road projects. Specifically, we discuss the criteria for and construction of artificial dens and road crossing structures. These measures, when judiciously applied, may increase fox survival, habitat connectivity, and likelihood of persistence of urban fox populations.

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INTRODUCTION

INFORMATION NEED

The San Joaquin kit fox historically occupied arid upland habitats throughout the San Joaquin Valley. Former and current conversion of these lands to agriculture, urban, and industrial uses has resulted in profound habitat degradation, fragmentation, and loss. As a result, the San Joaquin kit fox was listed as Federally Endangered in 1967 and California Threatened in 1973 (U.S. Fish and Wildlife Service 1998).

Kit foxes currently persist in a metapopulation consisting of 3 large "core" populations (Carrizo Plain National Monument, LoKern Natural Area, Panoche Hills region) and a number of smaller "satellite" populations. Movement of foxes between these populations is important for maintaining gene flow and avoiding inbreeding effects. Furthermore, kit fox populations exhibit marked fluctuations in the number of individuals as a result of natural and anthropogenic processes (e.g., Cypher et al. 2000). Risk of extinction due to catastrophic or random demographic events is increased for small populations in general and kit foxes specifically (White et al 2000). Thus, dispersal between populations may be necessary to prevent local extinctions or to recolonize lands where foxes are extirpated. The probability of long-term persistence of this species will increase with the number and stability of populations and the ability of animals to move between these areas.

Bjurlin and Cypher (2003) identified numerous potential impacts of roads on kit fox populations. While vehicle strike is the most obvious and documented, roads also may degrade or fragment habitat, increase chemical or noise pollution, alter prey or predator abundance, introduce invasive species, cause changes to fire regime, and increase human presence and development. The aforementioned have a variety of potential impacts on foxes, including mortality or morbidity, disrupted social ecology, reduced productivity, displacement, altered space use, inhibited dispersal, reduced genetic exchange, and decreased carrying capacity.

One study (Cypher et al., in prep) found few impacts of two-lane highways on kit fox ecology in natural lands. Probability of fox-vehicle collision was low, perhaps as a result of low traffic volumes (approximately 8,000 vehicles per day) and few vehicles during periods of peak fox activity. Similarly, there was no evidence that foxes avoided territories that bordered or crossed the roads, had decreased reproductive output along roadsides, encountered changes in availability or utilization of prey, or were more at risk from predation. Road presence, and associated human activity did significantly alter fire regime, increasing the frequency of wildfire, and changing native *Atriplex spp.* shrubland to non-native grassland. This change appeared to alter relative abundance of several *Dipodomys spp.*, the primary prey of resident foxes. Furthermore, distribution (and perhaps abundance) of the coyote (*Canis latrans*) also was altered, with coyotes preferentially utilizing shrub remnants (Nelson et al., in prep). Clearly, potential impacts by roads are diverse, and perhaps mediated by other ecosystem processes (i.e., fire). Furthermore, as road width, traffic volume, and speeds increase, the potential for direct impacts, such as vehicle strike will increase. Roads throughout the range of the San

Joaquin kit fox are increasing in traffic volume. Therefore, lack of direct impact on San Joaquin kit fox as reported above is not necessarily indicative of future relationships between the kit fox and human transportation networks. For a synthesis of the literature on road impacts on San Joaquin kit fox refer to Cypher (2000) and Bjurlin and Cypher (2003).

The highest density of roads, peak traffic volume, and greatest potential for impact to foxes occurs in urban areas. Urban kit fox populations in California minimally occur in Bakersfield, Taft, Santa Nella, and Coalinga. Reports from the public and carcasses collected opportunistically indicate that kit foxes are dying by vehicle strike in the human developments of the Southern San Joaquin Valley. Urbanized foxes may encounter roads while foraging, looking for mates, defending territories, and dispersing. Little is known, however, about the factors that influence where, when, and how vehicle strikes occur. Furthermore, it is unknown whether there are changes to kit fox use or placement of dens, patterns of movement, susceptibility to predation, prey selection, or other elements of fox ecology as a consequence of proximity to roads in urban areas.

Why is the impact of urban roads on kit fox populations important? First, urban areas have rapidly grown throughout the range of the kit fox. In some cases, development has occurred in agricultural lands that long have been devoid of kit foxes. But in many other cases, urbanization has displaced or altered fox populations occurring in natural lands. Conversion of natural lands permanently decreases availability of habitat, which is a major obstacle to species recovery. Second, the network of three core- and several satellite-populations identified in the recovery plan for this species is vulnerable to fragmentation associated with transportation networks. For this metapopulation to remain functional, individuals must be able to move between sub-populations. The potential for negative impact of roads on the ability of foxes to utilize corridors may be proportional to road width, traffic volume, and speed limit. Projections for the San Joaquin Valley indicate that the human population and associated urbanization and transportation networks will increase for the foreseeable future. The highest potential for fragmentation will occur in urbanized areas where roads are most prevalent. Third, as urban lands spread and natural lands diminish, urbanized fox populations may become more valuable to species recovery. Urban fox populations are relatively less susceptible to meteorological stochasticity, and may prove useful as a repository for genetic diversity and/or individuals for reintroduction efforts. Consequently, the influence of transportation networks on San Joaquin kit fox recovery is likely to grow simultaneously to the importance of urbanized fox populations where transportation networks are most prevalent. Identifying ways to reduce the impact of urban roads on the kit fox is therefore a conservation priority.

A less tangible, but still important, reason to reduce the impact of roads on urban fox populations is the interaction between urbanized kit foxes and the public. Standardized surveying shows that the citizens of Bakersfield (where the largest population of urbanized foxes occurs) generally have seen a kit fox on one or more occasions and support protection of the urban population (Bjurlin and Cypher, in press). Furthermore, respondents expressed widespread appreciation of urbanized foxes (in some cases becoming strongly protective). The greatest concern identified by respondents was that kit foxes would be killed by vehicle strike. Furthermore, fox-vehicle collision, or the attempt to avoid it, may in some cases contribute to traffic accidents (unconfirmed citizen report) or unsafe road conditions. Measures designed to minimize kit fox crossing of busy roads at grade are likely to receive strong public support. To the extent that pedestrian and fox crossing structures can be combined for multiple use, the perceived benefits of this investment in infrastructure are likely to increase.

GOAL

Our goal was to determine whether roads affect the ecology of the urbanized San Joaquin kit fox. From 1997-2004, we outfitted kit foxes with radio transmitters and monitored survival, den use patterns, and movements. We examined these data for statistical and spatial associations to urban road networks. Based upon these results we provide detailed recommendations for the protection of San Joaquin kit foxes in urban environments during and after road projects. If implemented, these recommendations are likely to contribute to the long-term viability of urban fox populations and species recovery, receive strong public support, and may even increase public safety.

STUDY AREA

The study site is located in the southwestern quarter of the Bakersfield metropolitan area (Figure 1). Bakersfield lies at the southern end of the San Joaquin Valley in central California and is the Kern County seat of government. The metropolitan area as of January 2003 was approximately 580 km^2 (224 mi^2) with 394,234 residents (http://www.bakersfieldchamber.org/pdf/community-profile.pdf). The urbanized area of Bakersfield grew by 23.6% from 1990-2000 and continued growth is expected (http://factfinder.census.gov/home/saff).

Hot, dry summers, and cool, wet winters characterize the climate of the southern San Joaquin Valley. Average daily maximum temperatures range from 14°C in December to 37°C in July and average daily minimum temperatures range from 4°C in December to 21°C in July (Meadows Field Airport weather station). Annual precipitation averages 14.3 cm, but varies greatly between years.

METHODS

Kit Fox Capture and Monitoring

From May 1997 to July 2004 we captured kit foxes in live traps, outfitted them with radio transmitters, and monitored them for sources of mortality, nightly movements, daily resting places, and reproductive output. We captured foxes with wire-mesh box traps (38 x 38 x 107 cm) baited with assorted meats. Traps were covered with cloth tarps to protect animals from inclement weather and direct sun. Captured foxes were examined for injury and parasites, ear-tagged, sexed, aged, and fitted with a radio collar (40g, Advanced Telemetry Systems, Isanti, Minnesota) containing a mortality sensor that altered signal pulse rate if the animal was motionless for four hours. We released foxes at site of capture after 0.5-1 hour of handling. Capture and handling protocols were in accordance with permits TE023496-1 and TE825573-2 from the U.S. Fish and Wildlife Service and a Memorandum of Understanding from the California Department of Fish and Game.

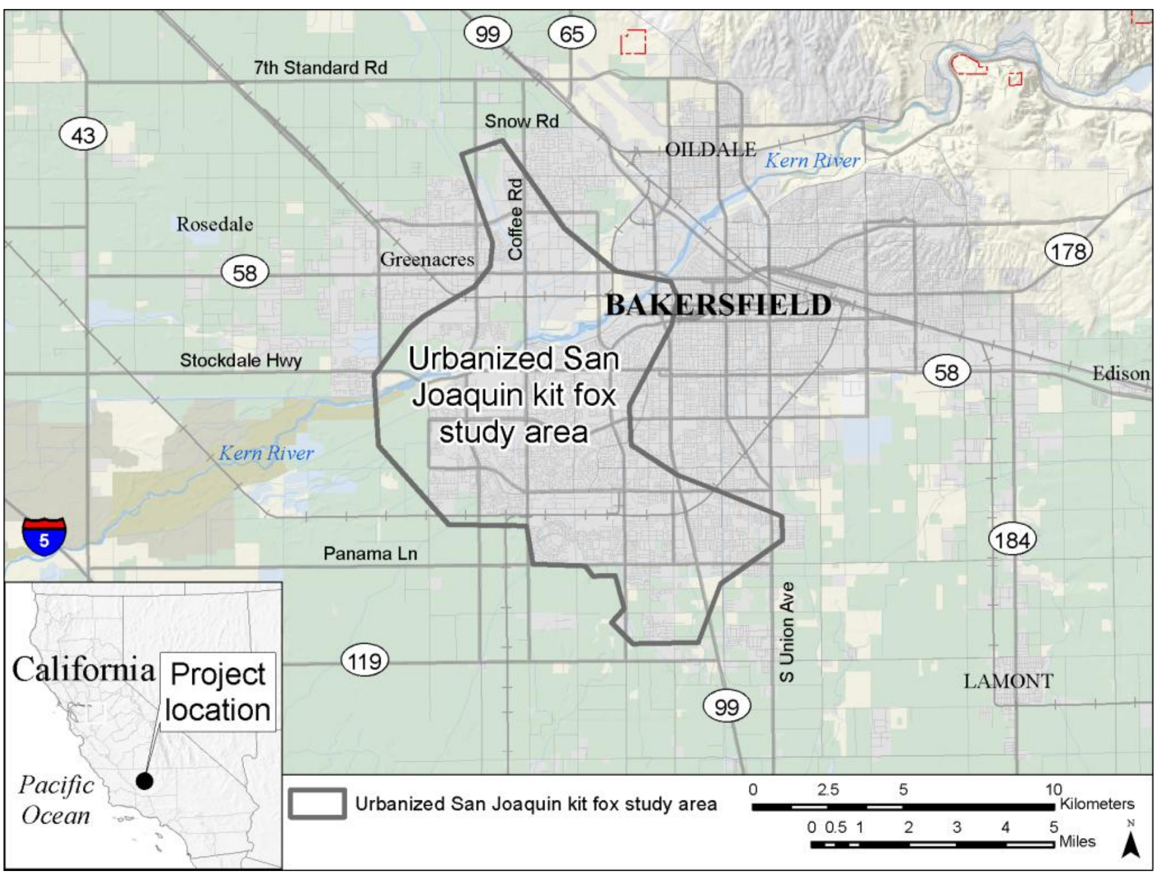

Figure 1. Urbanized San Joaquin kit fox study area, Bakersfield, CA.

At a minimum, we attempted to record one day-resting location and two night-activity locations for each animal with a functioning radio collar during each week. In some cases fewer locations were recorded because of collar failure, fox dispersal from typical home ranges, use of resting sites that attenuated radio signal, or other factors. Radio collar transition to mortality signal allowed us to promptly retrieve deceased foxes and increased the likelihood of confirming cause of mortality. Fox carcasses also were collected opportunistically during the study when spotted on roads, reported by citizenry, or collected by other organizations. Each spring, we conducted natal den observations to estimate litter size for all radio-tagged females. Finally, we collected kit fox feces for dietary analysis throughout the study duration. Locations of activity, mortality, resting, and pup whelping and rearing were recorded with GPS and entered in a GIS for spatial analysis.

MORTALITY

We conducted necropsy for all recovered fox carcasses. We limited our analysis of cause of death to animals that were actively being monitored with radio telemetry in order to decrease bias caused by differences in visibility of carcasses. We also report, however, on all carcasses retrieved during the study. Cause of death was determined using the pattern of injury, including external abrasion, broken bones, internal hemorrhaging, and bite wounds. The location that the carcass was retrieved from also was used in determining cause of death (e.g., within road right-of-way, buried at construction site, in carnivore scrape, etc.).

For all animals (transmitting or not) that died by vehicle strike, we assigned road type (local, collector, arterial, highway), traffic volume, and posted speed limit. Local roads had the primary purpose of providing access to abutting residential property, did not exceed 12.2m (40ft) in width, had no more than one traffic lane in each direction, and were not longer than 0.8km (0.5mile) without interruption. Speed limit was 25mph on all local roads, but was not always posted. Collector roads generally conducted local road traffic to the arterial road network, but sometimes were residential in nature. Speed limits (generally 30-45 mph) for collector roads were based upon speed surveys and were posted. Arterial roads had 1-3 lanes of traffic in each direction (typically more than one), carried the majority of city traffic, and connected the local and collector road networks to the State highway system. Arterial road speed limits (35-55mph) were always based on speed surveys and posted. Lastly, highways were State numbered roads with the primary purpose of conducting traffic into and away from the urban area. They included highways 58, 99, 178, and 119 and in some cases passed through residential, commercial, and industrial areas. Vehicle access to highway 99 and portions of 178 was by ramp only.

We compared road type where foxes died to an expected distribution based on road availability using contingency table analysis. Road availability was calculated by summing the length of three road types (local, collector, arterial) within the minimum convex polygon of the locations of vehicle strike (Figure 2). Vehicle strikes also were examined for temporal patterns. For this analysis we limited the time period to 6 complete years, 07/01/1998-06/30/2004 so that months wouldn’t be disproportionately represented. Strikes were separated by fox age (adult, juvenile) and gender (male, female) and compared with other sources of morality by month. Temporal distribution in strikes was compared with frequency of fox scent marking, interaction with foxes outside of social group (Murdoch 2004), and traffic volume by month.

Finally, we examined spatial patterns of kit fox vehicle strikes that occurred on arterial or collector roads. We had insufficient sample size to conduct similar analyses for local and highway strikes. We limited the extent of this analysis to southwest Bakersfield where we had the greatest knowledge of roads and fox habits. Strikes were examined for association with intersections of the road where the mortality occurred and other linear rights-of-way. Linear rights-of-way for this analysis were defined as other roads (local, collector, arterial, highway), canals, railroads, rivers, or golf course crossings.

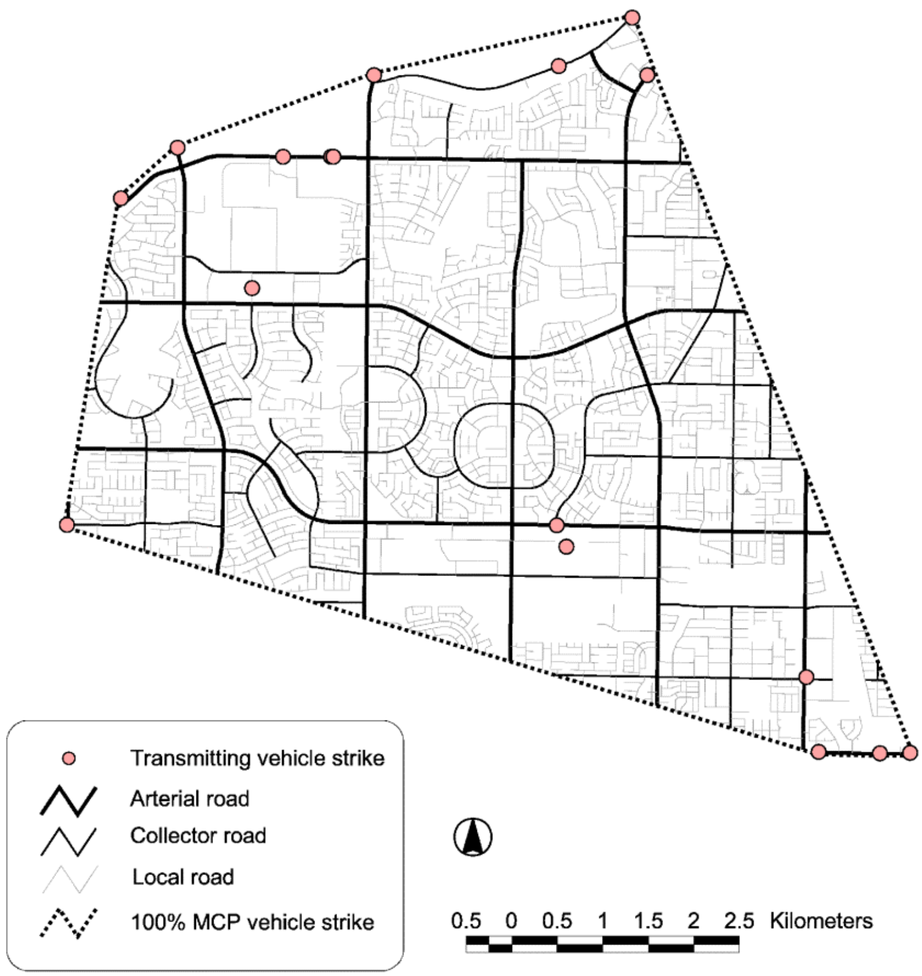

Figure 2. Minimum convex polygon of fox-vehicle collisions for individuals that had transmitting radio collars, Bakersfield, CA, 1998-2004.

In order to conduct this spatial analysis, we defined vehicle strike road segments. These segments were the shortest sections of road that were bounded by intersection with other arterial or collector roads and contained the vehicle strike location. This rule was modified when the mortality occurred at an intersection with arterial or collector road. In these cases, the segment was extended in both directions to the next, nearest intersection with a major road. We then assigned 100 randomly distributed points to the road segment for each vehicle strike. For example, if three strikes occurred on the segment, 300 randomly distributed points were assigned. We calculated the distance to nearest intersection with linear right-of-way for all points (confirmed strike and random). Distance was coded into three categories, near ($x <= 26$m), intermediate ($26m < x <= 52m$), and far ($52m < x$) based on a mean road width of 26m. Therefore, strikes assigned as "near" occurred within one road width of the intersection, as "intermediate" within two road widths, and as "far" greater than two road widths. Observed strikes versus random locations were examined with this coding scheme in a contingency table analysis for a departure from what would be expected by chance. Lastly, we evaluated the type of intersections where vehicle strikes occurred for strikes coded as "near". We then compared the frequency of observed mortalities and random points among intersection types.

DENS

Association between confirmed kit fox dens and major roads (highway, highway ramp, arterial, and collector) was examined for dens used by radio-collared foxes from 1 July 2001 to 30 June 2004. Distance to nearest road centerline was calculated for each known den and compared across distance categories (34.5m, 69m, etc.). Distance categories corresponded with Fish and Wildlife exclusion zone distances for known kit fox dens (34.5m = 100ft).

MOVEMENTS

Kit fox space use was studied using vehicle-based monitoring of focal animals during 2003. Focal sessions typically began 1 or more hours after nightfall (full dark) and lasted for approximately four hours. Every 15 minutes we attempted to collect a new location for the focal animal. We described fox locations as accurately as possible using a combination of triangulation and spotlighting. With these data we calculated minimum straight-line distance (MSLD) between consecutive locations. We also calculated rate of travel (MSLD km/hour). Finally, we estimated number of road crossings (arterial, collector, local) using MSLD and visual sightings. We then adjusted these data for crossing rate per hour of observation and MSLD of movement. We used shapefile coverages of city roads and geo-referenced aerial photography to assign road crossings for this analysis.

SPATIAL AND STATISTICAL ANALYSIS

Spatial analysis was conducted using ArcView version 3.2 (ESRI 1996). Data for roads and traffic volumes were generated with shapefile coverages from City of Bakersfield GIS and Traffic Engineering Departments, respectively (City of Bakersfield 2000-2004). All spatial data were projected in Lambert Conformal Conic, California State Plane, NAD27. In some cases data on road location, size, or posted speed limit was unavailable for the year in which the kit fox feature was described (i.e., vehicle strike, den, movements). In these instances data from the closest available time period were used (usually less than one year distant). Geo-referenced aerial photography (AirPhoto USA) was used to assign the location of road intersections with other linear rights-of-way. All statistical analyses were performed using SPSS version 11.5 (SPSS Inc. 2002) and results were considered significant at $P <= 0.05$.

San Joaquin Kit Fox

RESULTS

URBAN KIT FOX ECOLOGY

From May 1997 to July 2004 we captured a total of 358 individual foxes (109 adults, 206 juveniles, and 43 juveniles that were captured again as adults). Of these, we outfitted 229 individuals with radio collars (84 adults, 79 juveniles, and 66 juveniles that continued to be monitored as adults). We monitored radio-tagged animals until they died, transmitters failed, or they were lost. We collected 8,115 night activity locations and 6,647 daytime resting locations during the study (Figure 3a-b). Kit foxes primarily rested diurnally within dens, of which we described 471 over the study period. We located kit fox litters on 54 separate occasions. With these data we will conduct additional analyses on survival rates, reproductive rates, den site selection, space requirements, preferred habitats, and foraging patterns. We will present these data in a comprehensive monograph of kit fox demographics and ecology in urban environments. California Department of Transportation (Caltrans) will be supplied with a copy of the monograph and associated recommendations for the conservation of urban fox populations.

MORTALITY

We collected 156 kit fox carcasses from September 1985 to August 2004. Carcasses collected prior to 1997 were stored by California State University, Bakersfield. A near majority of mortalities were attributed to vehicle strike (48.1%, Table 1). These data, however, include animals that were received from a variety of opportunistic sources. By limiting analysis to animals that were actively being monitored with radio telemetry at time of death (N = 78) we reduce bias (e.g., differential reporting and accessibility to carcasses). Of this subset, confirmed vehicle strike accounted for 26.9% of mortality. An additional 7.7% of foxes may have died from vehicle strike, but evidence, while suggestive, was not conclusive. Predation (16.7%) was the second most common cause of death for transmitting animals. Other sources of mortality included entombment, poison, drowning, gunshot, complications during parturition, and entanglement.

Due to advanced state of decay or lack of gross injury, we were unable to determine cause of death for 28.2% of carcasses. However, 73% of the 22 individuals with unknown cause of death were retrieved from fox dens. Pertinent to this report, animals retrieved from dens were unlikely to have died of vehicle strike (they lacked broken bones or contusions), and therefore the percentages calculated for vehicle strike are considered accurate when unknown cause of death is included. Overall, 30.8% of the 78 mortalities of foxes with operational radio collars were retrieved from dens. In natural lands where most research has been conducted and mortality generally is attributed to predation, carcasses are rarely retrieved from dens. There may be sources of mortality in urban environments (e.g., disease or poisoning) that have yet to be identified, but that do not leave clearly diagnostic evidence with our necropsy techniques.

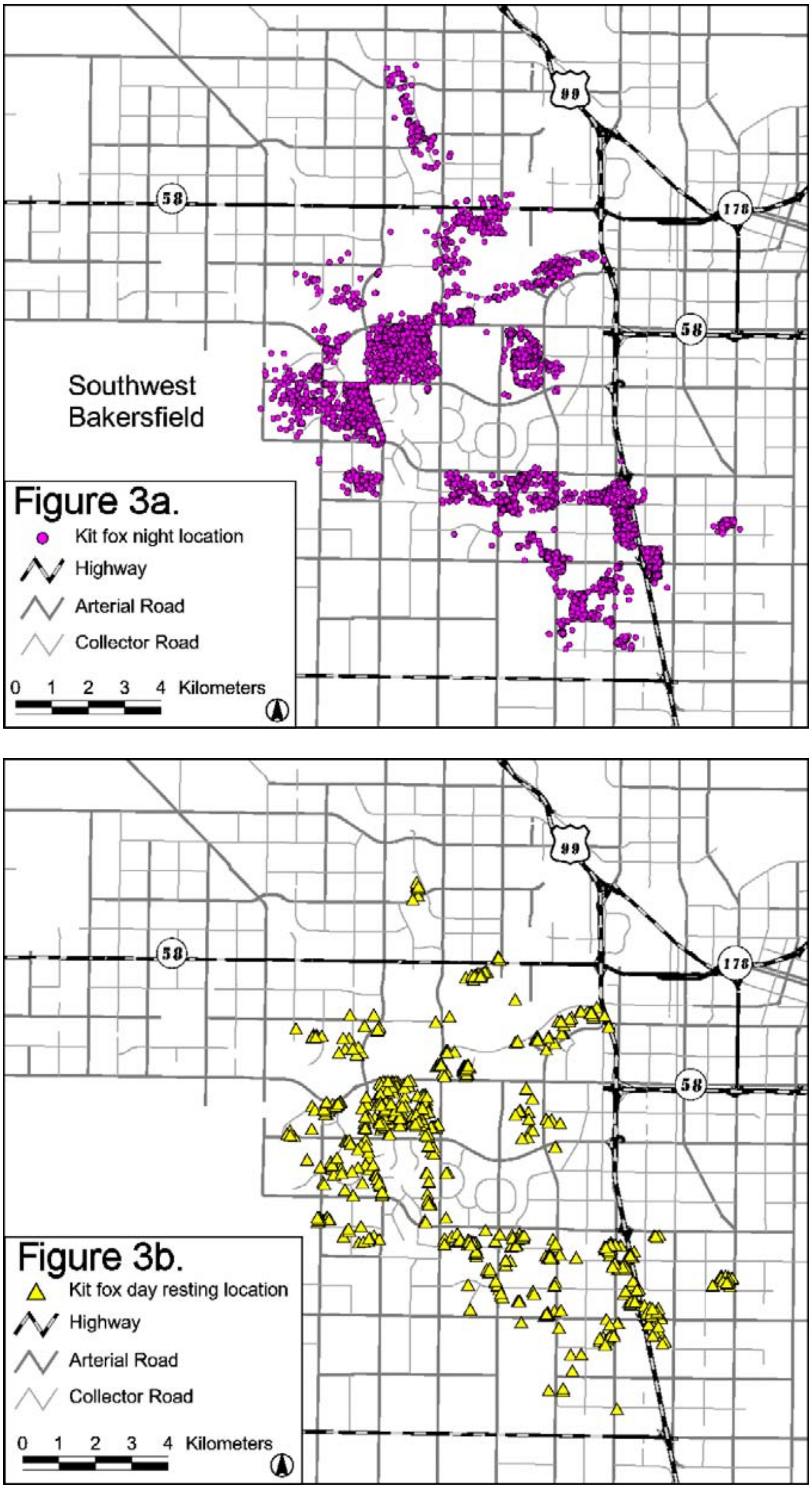

Figure 3. Nocturnal (a) and Diurnal (b) locations of San Joaquin kit fox in Bakersfield, CA, 1998-2004.

Table 1. Cause of death for all foxes (1985-2004) and foxes with transmitting radio signals at time of death (1997-2004), Bakersfield, CA.

Cause of Death	All Foxes		Transmitting Foxes	
	N	%	N	%
Entombed - construction	5	3.2	3	3.8
Entombed - natural	1	0.6	1	1.3
Poison	3	1.9	0	0.0
Possible poison	5	3.2	4	5.1
Predation	16	10.3	13	16.7
Possible predation	5	3.2	4	5.1
Vehicle	75	48.1	21	26.9
Possible vehicle	8	5.1	6	7.7
Other	6	3.8	4	5.1
Unknown	32	20.5	22	28.2
Total	156	100.0	78	100.0

Table 2. Frequency of fox-vehicle collisions by road type for all foxes and those with transmitting radio signals at time of death, Bakersfield, CA, 1998-2004.

Road Type	All Strikes		Transmitting Strikes	
	N	%	N	%
2-lane local	2	4.2	1	5.6
2-lane collector	8	16.7	1	5.6
2-lane arterial	2	4.2	1	5.6
4-lane arterial	17	35.4	7	38.9
6-lane arterial	16	33.3	7	38.9
6-lane highway	1	2.1	0	0.0
Not on road	2	4.2	1	5.6
Total	48	100.0	18	100.0

From January 1998 to August 2004, we had the necessary information on road status to describe association between road types and vehicle strikes. We retrieved 48 vehicle strike kit foxes in Bakersfield during this period. Of these, 18 were actively being monitored with radio telemetry at the time of death. Arterial roads accounted for 72.9% and 83.3% of strikes for all animals and actively monitored animals, respectively (Table 2). Collector roads, local roads, and highways were less significant sources of mortality. Within the 100% MCP of actively monitored animals (Figure 2), we identified 327.4 km of local roads, 49.9 km of collector roads, and 50.9 km of arterial roads. There was a significant difference between the observed frequency of roadkill by road type, and that which would be expected based on availability ($\chi^2_2 = 82.127$, $P < 0.001$). Arterial roads were far more often a source of vehicle strike than can be explained by chance occurrence.

Roads with four or more lanes accounted for 70.8% and 77.8% of roadkill for all animals and actively monitored animals, respectively (Table 2). Approximately 90% of roadkill were retrieved from roads with posted speed limits of greater than 45 mph, irrespective of whether the animal was transmitting at time or death or was collected opportunistically (Table 3). Roads with a 55 mph posted speed limit accounted for over half of all vehicle strikes. Mean traffic volume at vehicle strike was 21,861 and 23,426 vehicles per day for all strikes and actively monitored strikes, respectively (Figure 4).

Table 3. Fox-vehicle collisions by posted speed limit, Bakersfield, CA, 1998-2004.

Speed Limit	All Strikes		Transmitting Strikes	
	N	%	N	%
25 mph	1	2.1	0	0
35 mph	1	2.1	0	0
40 mph	1	2.1	1	5.6
45 mph	9	18.8	2	11.1
50 mph	6	12.5	5	27.8
55 mph	27	56.3	9	50.0
65 mph	1	2.1	0	0.0
Not on road	2	4.2	1	5.6
Total	48	100.0	18	100.0

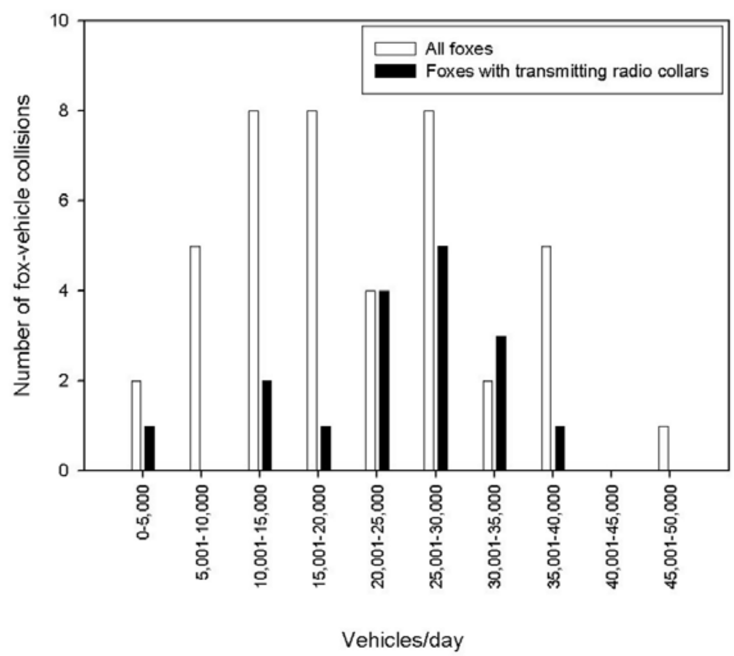

Figure 4. Fox-vehicle collisions by traffic volume for all mortalities and mortalities of individuals with transmitting radio collars at time of death, Bakersfield, CA, 1998-2004.

There was no overall interaction between vehicle strike as cause of death (Coded Yes/No) and gender ($\chi^2_1 = 0.057$, $P = 0.812$) or age ($\chi^2_1 = 0.709$, $P = 0.400$) for 78 foxes that were actively being monitored at time of death. Of 47 adult mortalities, 38.3% were either confirmed or possible vehicle strikes. Confirmed or possible vehicle strike accounted for 29.0% of 31 juvenile mortalities. Mortalities were evenly distributed between the genders (male = 39, female = 39), and approximately one third of each sex died of confirmed or possible vehicle collision. While all mortalities were distributed throughout the year, vehicle strikes showed a distinct peak in December during the six-year period beginning 1 July 1998 (Figure 5). Further examination showed an association between gender, age, and vehicle strikes when the data were examined temporally. Of nine foxes that died of vehicle collision in December, seven were adult males. The winter (December/January) spike in male fox-vehicle collision corresponded with male rate of scent marking (Figure 6) and overall rate of interaction between focal foxes and conspecifics that were not within the social group (Figure 7). Both scent marking and interaction frequency may be indicators of reproductive behavior and territoriality (Murdoch 2004). There also appeared to be a smaller increase in vehicle strike from May to September. Many of these animals were pups that were at the age typical of increasing independence from the natal group, solitary foraging, and dispersal. Vehicle traffic volume did not differ by month at six control stations spread across the urban area (Figure 8).

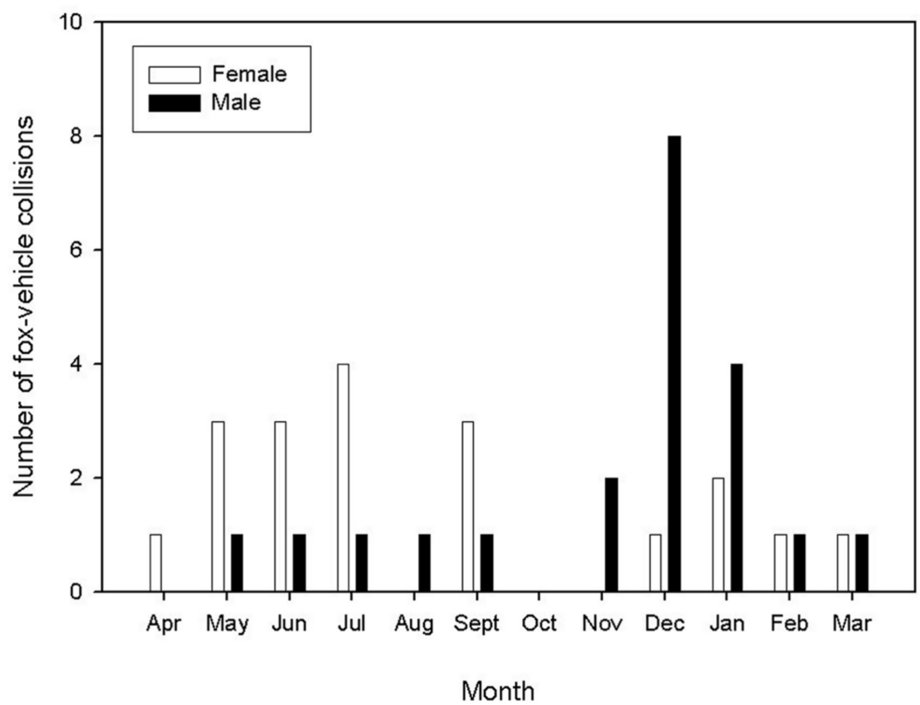

Figure 5. Fox-vehicle collisions by gender and month, Bakersfield, CA, 1998-2004.

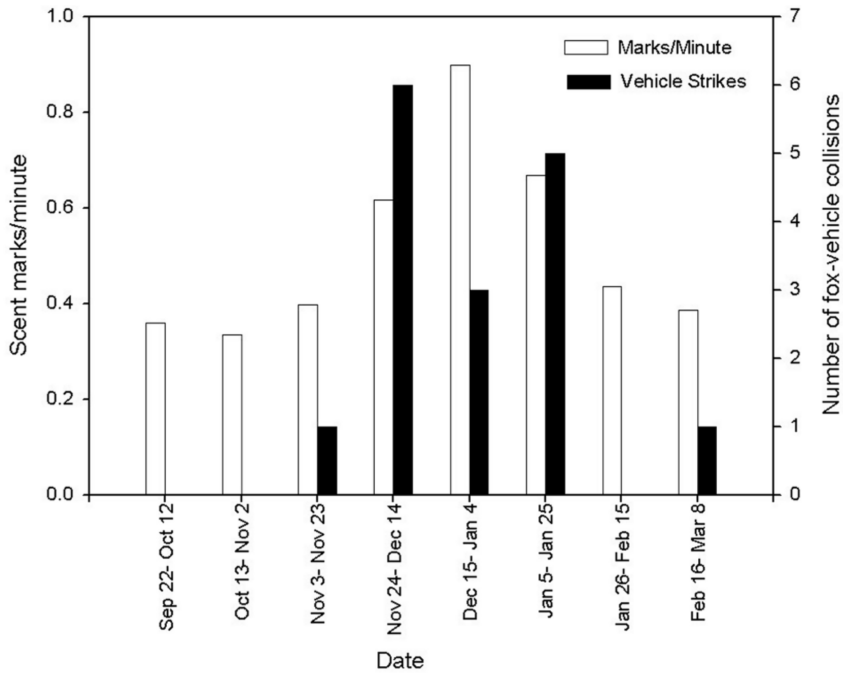

Figure 6. Fox-vehicle collisions (1998-2004) versus scent marking rates (Murdoch 2004) for male foxes, Bakersfield, CA.

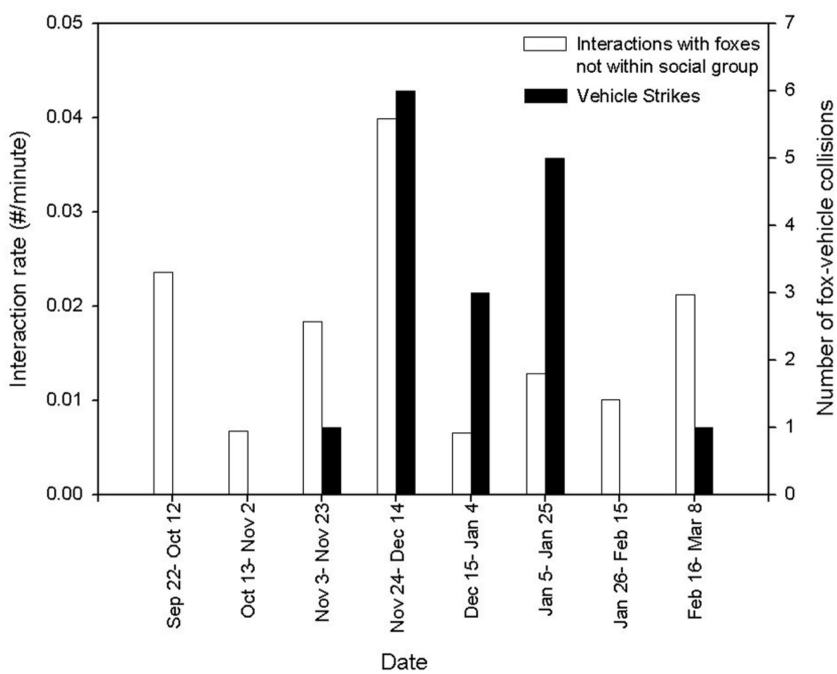

Figure 7. Fox-vehicle collisions (1998-2004) versus interactions with foxes that were not within the immediate social group (Murdoch), Bakersfield, CA.

We identified 23 segments of arterial or collector roads where strikes occurred. Number of strikes per segment ranged from 1 to 5 and accounted for 38 strikes in all (Figure 9). Along these segments we identified 136 intersections. Kit foxes died more often than expected by chance at intersections with a linear right-of-way ($\chi^2_2 = 15.75$, $P < 0.001$). Strikes within one road width (<=26m) of an intersection accounted for 47.3% of all roadkill. In contrast, only 22.5% of random points occurred within one road width of an intersection. Following a similar, but weaker, trend 21.1% of observed roadkill were between one and two road widths ($26 < x <= 52$m) of an intersection, versus 17.8% of random locations in the category. There did not appear to be a higher risk of strike at any one type of intersection. Across intersection types, frequency of vehicle strikes that occurred in the category nearest to intersections mirrored the frequency of random points (Table 4). For example, 38.9% of all strikes within one road width occurred at intersection with local roads, while 37.1% of corresponding random points occurred at local road intersections.

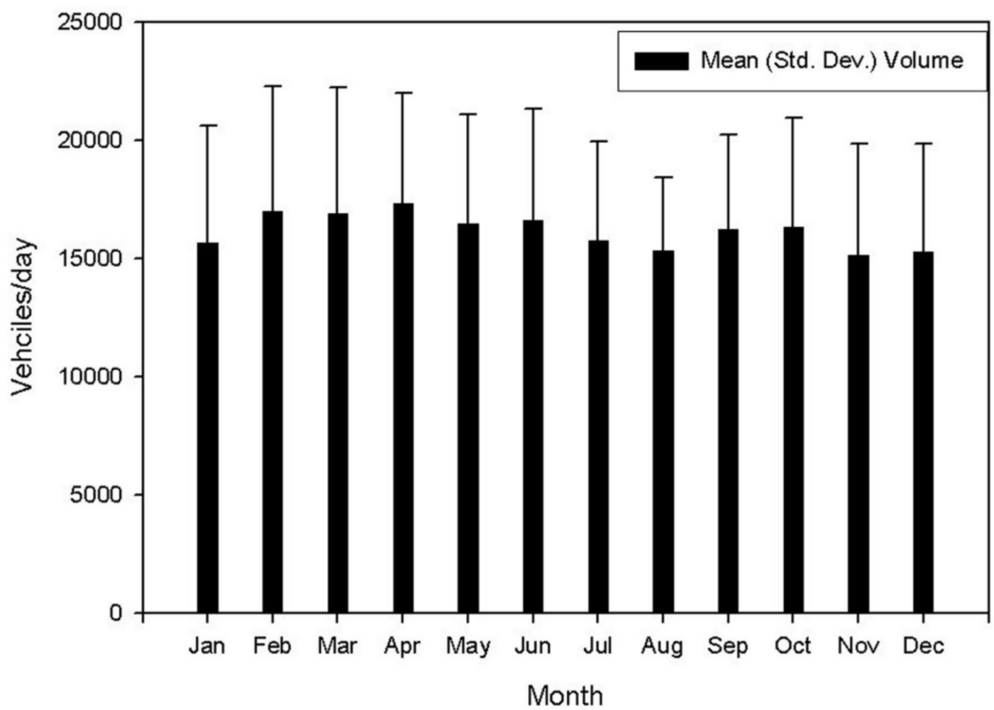

Figure 8. Mean (Std. Dev.) traffic volume by month at six control stations, Bakersfield, CA, 2003.

Table 4. Observed versus random generated fox-vehicle collisions on arterial and collector roads that were within one road width (26m) of an intersection with a linear right-of-way, Bakersfield, CA, 1998-2004.

Intersecting Linear Feature	Observed Strikes		Random Points	
	N	%	N	%
Arterial road	1	5.6	99	11.6
Canal	4	22.2	191	22.4
Collector road	3	16.7	69	8.1
Golf course	1	5.6	59	6.9
Highway	1	5.6	58	6.8
Local road	7	38.9	317	37.1
Railroad	0	0.0	17	2.0
River	1	5.6	44	5.2
Total	18	100	854	100.0

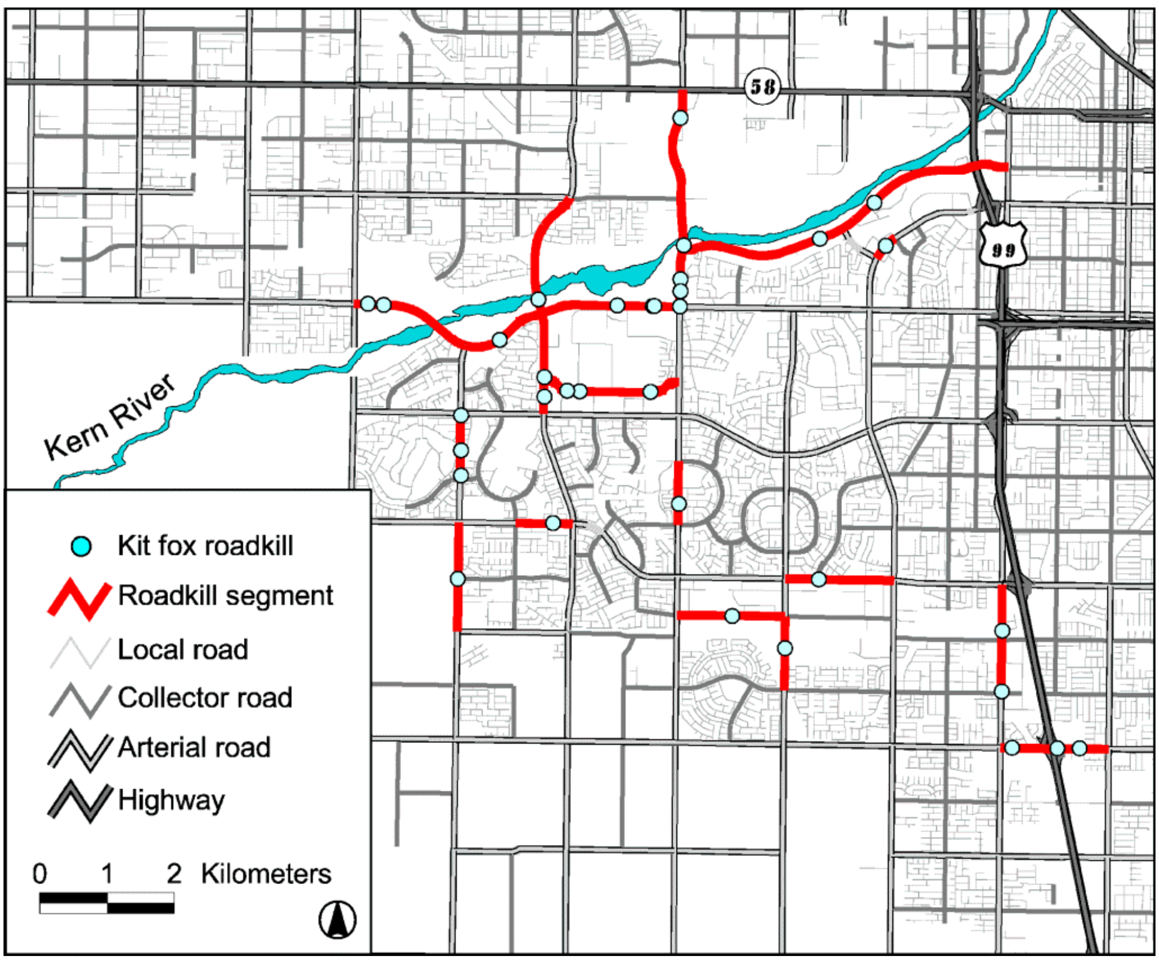

Figure 9. Fox-vehicle collisions and road segments where mortality occurred, Bakersfield, CA, 1998-2004.

DENS

Kit foxes did not appear to avoid using dens or building dens at sites that were adjacent to major roads. We calculated nearest major road (arterial, collector, highway, or highway ramp) to each of 327 fox dens used from 1 July 2001 to 30 June 2004. Of these, 9.5% occurred within 30.4m (100ft) of the nearest road centerline. A similar trend occurred for each subsequent 30.4m distance from road (Figure 10). Some foxes utilized features of a major road for den construction. One individual was known to den within a culvert beneath highway 99 (Figure 11). Other dens occurred in the embankments or underpasses of a raised portion of highway 99 (Figure 20b, Appendix), and at drainage basins (e.g., Figure 14c, Appendix) or canals directly adjacent to roads.

In some cases dens were directly adjacent to the roadway (Figure 12), but in other cases roadside dens were behind by a cement block wall or other barrier that increased isolation, decreased noise pollution, and may have made the site less likely to be impacted by human activity (Figure 13). Dens directly adjacent to roads are at risk of disturbance during road maintenance or construction. Four dens within a drainage basin at the intersection of two arterial roads (Figure 14c) were destroyed during earth moving associated with road widening and improvement. In fact, the entire drainage basin was removed in this instance. Four frequently occupied fox dens were destroyed when a local road, Kroll Way, was extended through a previously un-roaded area.

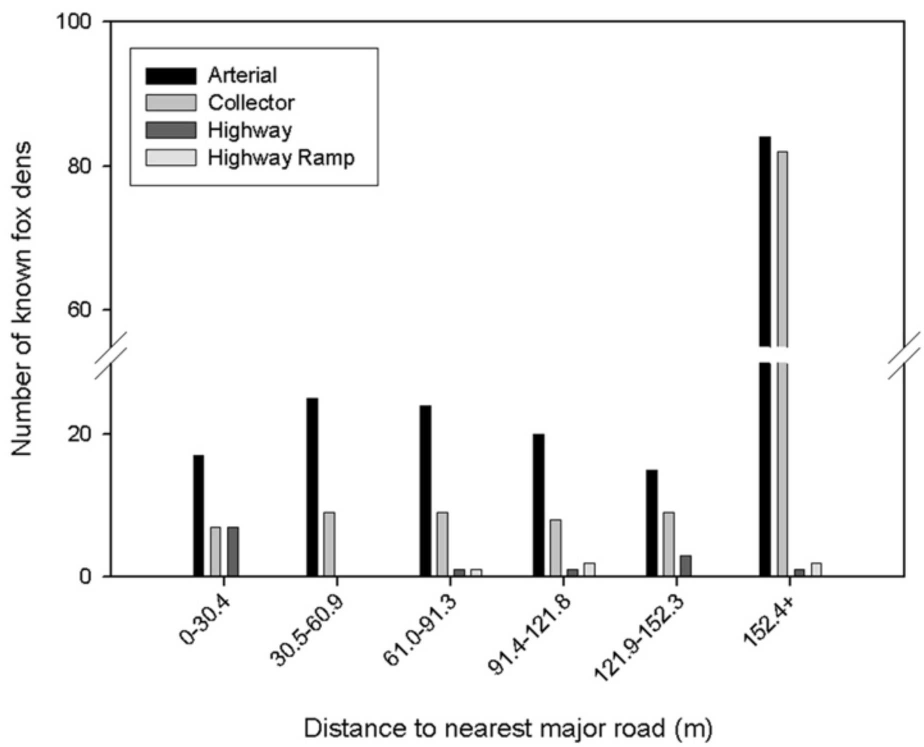

Figure 10. Number of known dens by distance to nearest centerline of major road, Bakersfield, CA, 2001-2004.

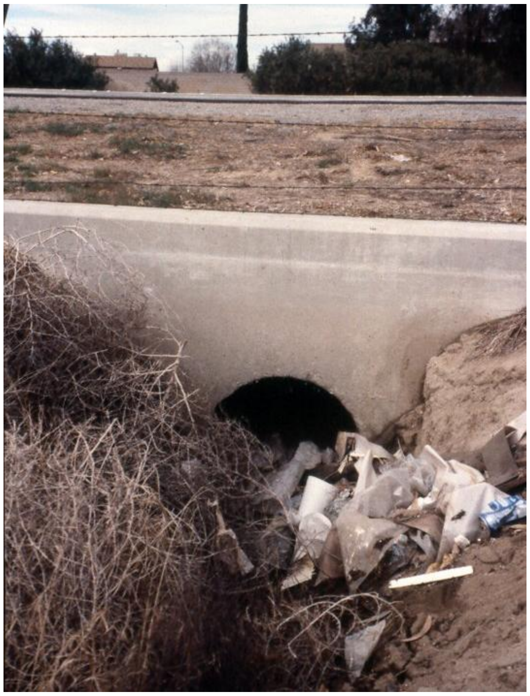

Figure 11. Drainage culvert under Highway 99 in Bakersfield, CA that was used as a den by San Joaquin kit fox.

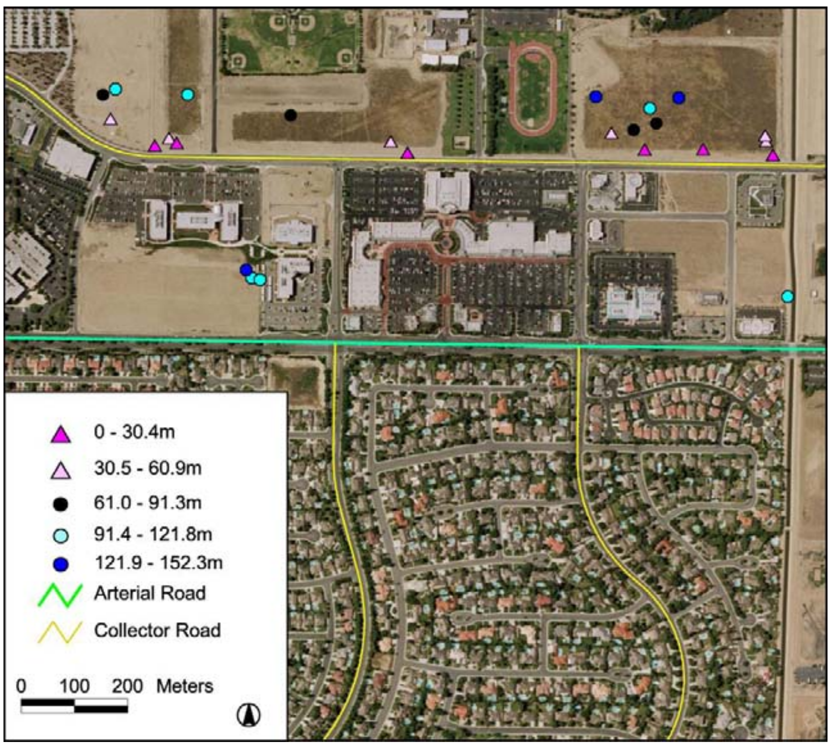

Figure 12. Kit fox dens at varying distances from collector and arterial roads in Bakersfield, CA, 2001-2004.

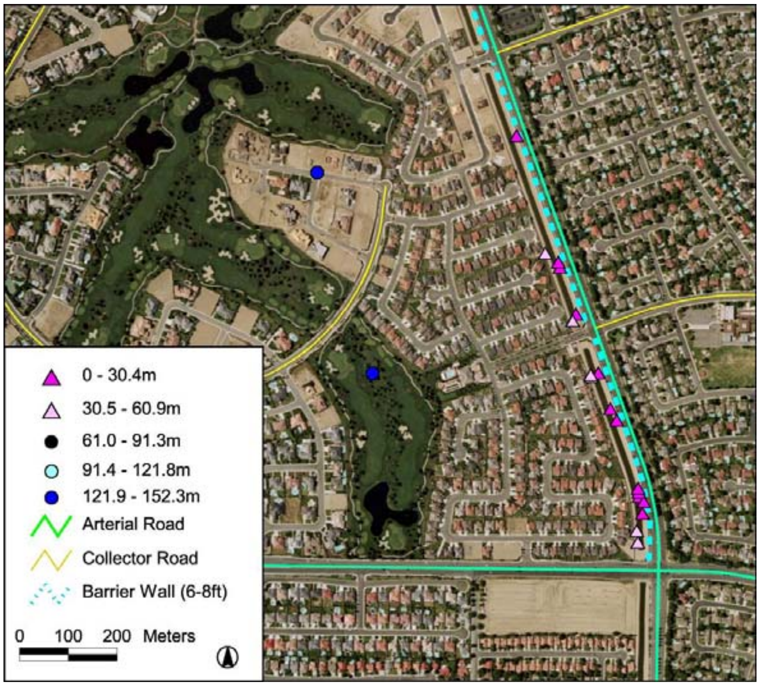

Figure 13. Kit fox dens at varying distances from collector and arterial roads, Bakersfield, CA, 2001-2004. A barrier wall, indicated with dashed line, isolated dens from one roadway with relatively high traffic volume.

MOVEMENTS

We conducted 21 sessions of vehicle-based intensive monitoring on 15 different focal kit foxes, for a total of 4,633 minutes of observation. We collected an average of 16.2 unique locations per session. Mean interval between locations was 15.14 minutes. By connecting these locations sequentially, we were able to calculate minimum straight-line distance (MSLD) moved and minimum rate of travel. We recorded a total of 44,121m of MSLD, for an average of 2,101m per monitoring session. Using MSLD and observation time, we calculated that foxes traveled at an average rate of 0.5958 km/hr during monitoring. Of course, focal foxes were inactive during much of the focal period and minimum distances between points do not account for the more complex travel patterns that were likely to exist. Therefore, foxes traveled a greater distance in shorter time and actual rate of travel likely was considerably higher.

MSLD movements also allowed us to estimate number of road crossings during focal sessions. We directly observed foxes crossing local roads on 10 occasions and arterial and collector roads on one occasion, each. MSLD predicted that foxes made 108 road crossings during focal monitoring. The majority (79 crossings) occurred on local roads, while 12 and 17 crossings occurred on arterial and collector roads, respectively. On average, foxes made 2.43 road crossings per km MSLD and 1.46 crossings per hour during intensive monitoring. Crossing rate for arterial roads (the primary location of roadkill) dropped to just 0.32 and 0.16 crossings per km MSLD and hour, respectively. Intersection of arterial roads with MSLD occurred in only six monitoring sessions (five individual foxes).

DISCUSSION

MORTALITY

As the single largest source of mortality for the Bakersfield fox population, vehicle strike clearly is an important factor for urbanized foxes. These data are in marked contrast with all other studies on kit fox in which vehicle strike rarely exceeded 10% of mortalities and was not considered a significant influence on fox demographics or population ecology (Bjurlin and Cypher 2003). In the largest study to date on the San Joaquin kit fox in natural habitats, Cypher et al. (2000) found that predation accounted for 57.2% of 222 fox deaths while vehicle strike was identified as cause of death in only 9% of occurrences. In contrast, predation during this urban study accounted for 16.7% of mortality, while vehicle strike, at 26.9%, was a more important cause of death. The coyote is the primary predator and competitor of the San Joaquin kit fox (Ralls and White 1995, Cypher and Spencer 1998) and is not abundant in Bakersfield (Cypher unpubl. data). Coyote distribution appeared limited to the Kern River corridor in the urban area included in this study. Therefore, it is possible that vehicle strike simply replaces mortality that would otherwise have been caused by depredation, had predators been more abundant. Indeed, some urban fox populations have persisted for decades and appear relatively stable given the dynamic alteration of urban environments that occurs during development and land conversion. Analyses of urban fox population viability and the impact of vehicle strike on viability are pending.

Arterial roads accounted for most strikes, a relationship that was significantly different from expected based on availability of this road type in the urban environment. Arterial roads typically have multiple lanes, relatively higher traffic volumes, and relatively higher posted speed limits. The San Joaquin kit fox is capable of rapid travel over short distances. The swiftness of this species may enable it to safely navigate two-lane roads where vehicle speeds and traffic volumes are lower. Indeed, only 10% of strikes occurred on roads that had posted speed limits that were lower than 45 mph. Low volume and speeds on local roads make it less likely that a fox crossing the road will need to avoid more than one vehicle. In contrast, a fox crossing four- or six-lane roads may have to evade multiple vehicles, which may travel in different directions and at different rates. Average traffic volume for urban roads with fox-vehicle collisions was nearly three times the volume of two-lane highways that transverse the LoKern Natural Area, one of three core areas for the San Joaquin kit fox (Cypher et al. in prep).

The incidence of vehicle strike was not evenly distributed. Foxes died more frequently within one road width of intersections between major roads and other linear rights-of-way then expected by chance. In fact, 68.4% of strikes on major roads occurred within two road widths of an intersection. The association between intersections and vehicle strike likely was the result of kit fox movement patterns. Species of the family Canidae (dogs, wolves, coyotes, foxes) utilize linear features for travel (Trewhella and Harris 1990), and we observed urban kit foxes on linear corridors between habitat patches (C. Bjurlin, pers. obs.). Additionally, increased traffic at intersections and regular changes in vehicle speed or direction (particularly where two roads come together) could make navigating intersections confusing for foxes. Finally, roadways typically are wider at road/road intersections to accommodate turning lanes. Greater distance to traverse equals greater time on the road and greater exposure to fox-vehicle collision. The lack of association of fox-vehicle collision with a specific type of intersection suggests that this relationship is broadly applicable.

Fox gender also was linked with vehicle strike when time of year was added as a variable. Males appeared particularly vulnerable during the breeding season (Dec-Jan). Increases in male strikes closely mirrored rate of scent marking and interaction with animals outside of the social group (Murdoch 2004). During the reproductive season, male foxes are more active, travel greater distances, are more aggressive, and spend more time chasing females in courtship and males in territory defense (C.Bjurlin, pers. obs). Furthermore, male foxes travel outside of the home territory in search of mating opportunities during December and January (Cypher et al., unpubl. data). One male in particular made these movements nightly for a period of a week and was observed successfully mating with a female in these new territories. While this example stands out in its detail, many males were observed in extra-pair copulation and outside of the typical home range during this study. On one occasion we witnessed four foxes in rapid and aggressive chase make their way through traffic on a collector road where several mortalities were known to have occurred. As interloper, transient foxes have to contend with similar agonistic interactions with resident males. It is likely that animals occupied with mating, aggressive interactions, or in unfamiliar territory are less aware of roads and traffic.

Vehicle strike during winter months also may be affected by shorter days and daylight savings time. Peak traffic volume occurs during morning and evening commutes. In the winter, the evening commute occurs up to two hours after sunset when male foxes are likely active and seeking mates. Fox activity and peak traffic volume have the greatest likelihood of overlap on the winter solstice (the shortest day of the year). Male vehicle strikes also appeared to be centered on the solstice. In contrast, traffic volume was constant throughout the year, so it is unlikely that monthly changes in traffic (e.g., holiday travel) contributed to patterns of fox mortality.

DENS

Kit foxes did not appear to prefer or avoid dens with respect to roads in urban environments. Urban land use is non-random and areas of similar zoning often are clumped. Kit foxes have shown preference for den sites with respect to some land uses. Of the 471 dens described from 1997-2004, 36.3% were located along the banks of canals or water detention basins. These areas, however, accounted for only a small percentage of available land area in Bakersfield. It appears that open spaces, or lightly and infrequently disturbed areas (such as canals and basins) are more influential on kit fox den site selection than the proximity or size of adjacent roadways. It is possible that a positive or negative association with roads may occur as a result of a relationship between roads and other, desirable den sites. For example, many of the water transport canals in Bakersfield are adjacent to major roadways. This pattern may reflect a planned strategy, simple convenience, or historical artifact of past development. There is no current strategy for land planning in urban areas with regards to the San Joaquin kit fox.

Therefore, future development practices may increase or decrease the likelihood that foxes will select den sites near roadways.

Den proximity to major roads may elevate the risk of mortality in some cases. One family group along a collector road in Bakersfield lost two of nine juveniles to vehicle strike in 2004. The natal dens in this instance were less than 20m from the road. Kit fox pups are active and relatively naïve to external dangers, particularly in the first six months of life. Urban foxes also quickly habituate to human and vehicle presence. While the process by which juvenile foxes learn how to successfully cross roads is unknown, there likely is a period of learning and perhaps elevated risk during youth, particularly when juveniles increase in independence and begin to venture farther from the natal site in search of prey and territory.

Fox dens are destroyed during road construction or modification. Because dens are an essential resource for the kit fox (see Appendix), development projects should avoid dens whenever possible, compensate for den destruction, and secure the necessary permissions from State and Federal authorities when altering lands upon which kit fox exist. In particular, kit foxes can be entombed within dens during earth moving. Road construction projects in Bakersfield have the potential to affect 9.5% or more of dens that occur within 100 ft of major road centerlines. The percentage of affected dens would have been far greater had local roads been included in this analysis. The Fish and Wildlife Service requires that an exclusion zone be created around these dens unless permission is given for den disturbance or destruction. The loss of den sites also decreases the general suitability of habitat, both for resident and for transient animals. Whenever dens are potentially affected by transportation projects, we strongly encourage the supplemental protection and compensation strategies that are described in the appendix to this document.

MOVEMENTS

Our data on the movements of radio-collared animals show that kit foxes frequently cross roads. The majority of crossings occurred on local roads, mirroring their relative abundance in urban areas, but the majority of mortalities occured on arterial and collector roads. Clearly, the low traffic volumes and speeds associated with local roads decreases the danger to kit fox. While these road types, cover extensive area with the range of the fox (thereby decreasing habitat availability), loss of habitat in urban areas may be unavoidable. We do not proposal specific conservation measures for local road construction to decrease fragmentation of urban landscapes.

Arterial and collector roads offer a greater challenge. These roads accommodate an ever-increasing volume of traffic in Bakersfield and other southern San Joaquin Valley human population centers. Kit foxes have shown that they can successfully cross major roads, but many animals maintained territories that did not bring them into frequent contact. It is unclear how increases in traffic volume affect the ability of animals to disperse in urban environments, which is a critical function for healthy kit fox populations.

Crossings appear to be habitual in some cases – with individual foxes repeatedly using a few locations to navigate the roadway. That and the association between fox crossings, fox-vehicle collisions, and linear rights-of-way suggest that these intersections would be likely candidates for conservation measures. While reducing speed limits and road sizes would not be practical, it may be possible to reduce the likelihood of vehicle strike on arterial and collector roads by providing safe passage for foxes. Specifically, we propose that road modification projects include wildlife crossing structures where appropriate. Criteria for selecting locations for crossing structures and instructions for building structures and associated infrastructure are provided in the appendix to this document.

CONCLUSIONS

Roads impact urban kit foxes. Fox-vehicle collision was the primary cause of mortality over a six-year intensive study of urban fox ecology. Because of the absence of predators in the urban environment, it is unclear whether vehicle strike was a limited factor for fox population growth, or simply a compensatory source of mortality for animals that would have been depredated had predator populations been robust. Analyses of survival and population viability are pending. Fox-vehicle collision spiked during the December reproductive season for male kit foxes. This spike in mortality may disrupt kit fox reproductive ecology by destabilizing pair bonds directly prior to whelping and rearing of young. Fox-vehicle collisions occurred more frequently than expected within one road width of an intersection with a linear right-of-way. Rights-of-way may be natural crossing locations for foxes due to habitual travel patterns. They also may be difficult to navigate safely due to wider roadways and irregular traffic speeds and directions. Kit foxes denned on roadsides at similar densities to more remote locations. Likewise, fox movements did not appear overtly affected by roads. Our study, however, was not specifically designed to test for an impact of roads on fox home range and dispersal patterns. An impact on either of these aspects of kit fox ecology is therefore unknown. The effects of road construction and modification may be reduced by the installation of artificial dens and wildlife crossing structures as outlined in the appendix to this document. Efforts to conserve urban fox populations will contribute to the recovery of this endangered species. Because fox-vehicle collision is the primary source of mortality for urbanized foxes, changes to roads that decrease fox death should command a central role in future conservation programs.

FUTURE RESEARCH

Based on the studies conducted to date by ESRP, further research and conservation efforts will benefit urban kit foxes. We have identified five topics for future investigation.

1) The factors that affect the suitability of urban habitats for kit fox are currently unknown. These factors may include road density, landuse (e.g., zoning), building density, and presence of refugia and/or corridors between habitat patches. A systematic census of kit fox in urban habitats (e.g., Bakersfield, Taft, Coalinga) using camera or hair traps is required to focus conservation and mitigation efforts in the areas that are of highest value. Previous urban fox research, while critical to identifying vital rates (births, deaths, migration), was not designed to rigorously test the variables that affect fox presence. Therefore, there is a significant data gap in this area.
2) Cause of death could not be determined for a number of foxes, and poisoning was strongly suspected in many of these cases. This question warrants further investigation to identify the types and sources of poisoning.
3) A recent pilot study has indicated that striped skunks, which are a host to rabies in the San Joaquin Valley, may present a future epidemiological threat to kit foxes in urban environments. Further research is required to quantify this threat and develop strategies to ameliorate it.
4) Conservation strategies have been identified that could potentially benefit urban kit foxes, such as road crossing structures, artificial dens, passages through walls and fences, and the construction of refugia and corridors in urban landscapes. Further research on the efficacy of these strategies, and information packages detailing these strategies, would benefit urban kit foxes, city planners, and developers.
5) A recent survey indicated that Bakersfield residents harbored misconceptions regarding kit foxes and their population status (Bjurlin and Cypher, in press). Resources directed toward developing and evaluating a coordinated outreach effort will benefit kit fox conservation in both urban and natural environments.

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APPENDIX. SUPPLEMENTAL RECOMMENDATIONS FOR PROTECTION OF SAN JOAQUIN KIT FOX DURING ROAD PROJECTS IN URBAN ENVIRONMENTS

Prepared by: Endangered Species Recovery Program
in cooperation with: U.S. Fish and Wildlife Service, Sacramento Field Office
and the California Department of Transportation

July 2005

INTRODUCTION

The San Joaquin kit fox (*Vulpes macrotis mutica*) was listed as Federally Endangered in 1967 and California Threatened in 1973. Specific measures implemented to protect the kit fox for any given project shall be determined by the U.S. Fish and Wildlife Service (Service) based upon applicant consultation with the Service. The purpose of this document is to provide an introduction to measures that may reduce impacts of road construction or modification in urban environments. Specifically, we discuss the criteria for and construction of artificial dens and road crossing structures. The measures outlined in this document are supplemental to standard Service and Caltrans guidelines, which will not be repeated here. Furthermore, these procedures are subject to modification or revision at the discretion of Service. The recommendations made in this appendix are those of the authors and are based on the findings of this research project and other current knowledge of the San Joaquin kit fox. These procedures are applicable to all urban environments where kit foxes are present or will be present in the future. Kit fox presence has been confirmed in Bakersfield, Taft, Santa Nella, and Coalinga, but surveys have yet to be conducted elsewhere. Kit foxes are likely to be found now or in the future in other urban or urbanizing areas.

DEN DISTURBANCE

Summary

Dens are a vital resource to the kit fox in urban environments (Koopman et al. 1998). Dens provide refuge from predators and climatic extremes, and a location to whelp and rear young. Urban kit foxes typically occupy dens diurnally, but may spend considerable time within dens during the night, especially immediately preceding parturition and in the months post-parturition when young are nursing and vulnerable to predation. In the following text we describe kit fox dens in urban environments and make recommendations for the treatment of dens when they are encountered at a work site. In addition, we provide criteria and instructions for the creation of fox-specific artificial dens. The construction of artificial dens may in some cases offset the destruction or disturbance of dens or fox habitat during road projects.

Urban Kit Fox Den Description

Many Federal guidelines pertain to the “known den” (U.S. Fish and Wildlife Service 1999). A known den is defined as any existing earthen den or manmade structure that is used or has been used at any time in the past by a San Joaquin kit fox. Evidence of use may include historic records, past or current radio telemetry or spotlighting data, kit fox sign such as tracks, scat, and/or prey remains, or other reasonable proof that a den or structure is being or has been used by a kit fox. The U.S. Fish and Wildlife Service discourages use of the terms ”active” and “inactive” when referring to a kit fox den because occupied dens may show no evidence of use, and because kit foxes change dens often, with the result that the status of a given den may change frequently and abruptly.

Known dens in urban environments take a variety of forms. Most dens are earthen and have multiple entrances, occur in vacant or undeveloped lots, and appear similar to dens found in natural lands. Many earthen dens in urban environments, however, occur at atypical locations, such as dense landscaping, maintained lawns, building foundations, stacked materials, and canal, drainage basin, road or railroad embankments (Figure 14a-d).

Kit fox use of manmade structures presents a further complication when assessing fox presence in urban environments. Kit foxes regularly den within pipes, under storage containers, buildings with raised foundations, stacked materials, vehicles, or any other structure or object that offers shelter and is large enough for a fox to enter (Figure 15a-d). Manmade structures may be permanent or temporary and may be occupied by kit fox for a single night or habitually. There may be little or no indication that a fox is present at the site. Because these features often are large and provide shelter without digging, typical sign of fox presence, such as dirt mounds, prey remains, or tracks, may be absent or obscured.

Detection and evaluation of kit fox dens in urban environments is challenging. Access to affected or adjacent properties may be restricted at the time of surveying. Irrigation associated with landscaping may degrade dirt mounds, prey remains, and tracks. In some cases dense thatch entirely obscures den entrances (Figure 16a-c). All potential earthen and manmade structures should be thoroughly inspected for sign of kit fox occupancy. In addition to standard procedures, the use of track plates and/or fiber-optic burrow probes may be necessary. Lastly, it is recommended that the surveying biologist interview local landowners, employees, and passersby about kit fox presence, den occupancy, and historic use of a potential project site. Local citizens often will have useful information on kit fox activity and habits that can focus survey efforts.

Natal dens, or dens where whelping and rearing of young occur, present a special circumstance that warrants increased protection. If a natal den is detected within or adjacent to the project site, all activities should immediately stop and the appropriate authorities should be notified. Natal dens typically have more entrances, tracks, scat, prey remains, and human garbage, and may have a broader apron of matted dirt and/or vegetation at one or more entrances (Figure 14b). As with non-natal dens, they may occur in a wide range of circumstances, from earthen dens more typical of natural lands to manmade structures where presence of the family group is difficult to confirm without direct observation of young. If interviewed, local citizens often will provide detailed information on the whereabouts and historic use of natal dens.

Artificial Den Description

Every effort should be made to avoid destroying or damaging known dens during project activities, as per standardized recommendations by U.S. Fish and Wildlife Service (e.g., surveys, monitoring, and exclusion zones; U.S. Fish and Wildlife Service 1999). Den destruction may at times be unavoidable. Consultation must occur prior to disturbance or destruction of den sites. While careful excavation may reduce the potential for direct mortality, loss of den sites has long-term negative effects that reduce the quality and viability of urban environments for kit fox.

The construction of artificial dens is a recommended mitigation for the disturbance or destruction of earthen or manmade kit fox dens during project activities. Artificial dens are of two types: subterranean and escape. Subterranean dens consist of two entrance tunnels (3-m length of 20-cm diameter polyvinyl chloride or high-density polyethylene pipe) leading down at no more than a 30-degree angle to a subterranean chamber (0.5 m in diameter, 0.3 m tall). Entrance tunnels should be oriented such that water does not flood the chamber. It is also recommended that a longitudinal section of the tunnel floor be removed to increase drainage and provide better footing for foxes that are exiting the chamber. The floor of the chamber should be located approximately one meter below ground. The chamber may be either box- or dome-shaped, but must have an earthen floor that allows kit foxes to enlarge the den over time (Figure 17a-d).

Escape dens consist of 3- to 6-m lengths of 20-cm diameter pipe (polyvinyl chloride or high density polyethylene) placed on the surface of the ground and covered with 1-2 m of soil (Figure 18a-d).

Both subterranean and escape dens can be modified to exclude entrance by larger predators, particularly red foxes (*Vulpes vulpes*) and coyotes (*Canis latrans*). These predators could be excluded by narrowing the den entrances to a width of 10-15 cm. This can be accomplished in a variety of ways, such as driving stakes in front of the entrances, or installing prefabricated diameter-reduction couplings.

Artificial subterranean and escape dens are regularly used by kit foxes in urban environments for resting, predator avoidance, avoiding temperature extremes, moisture conservation, and rearing of young. From June 2001 to June 2004, 22 subterranean and 9 escape dens in urban Bakersfield, CA were monitored using tracking media, remotely-triggered cameras, and radio telemetry (Cypher et al., unpublished data). Kit foxes used 29 of the 31 dens during the study period. These dens were checked with tracking media 8548 times, and fox tracks were detected on 1198 occasions (14%). This rate of visitation was a minimum estimate because precipitation, irrigation, and visitation by other animals at times made detecting kit fox tracks difficult. In spring 2003, and again in spring 2004, two different family groups raised young in artificial subterranean dens (Figure 19a-b).

Artificial Den Installation Criteria

The following criteria should be met when selecting locations to construct artificial dens.

1) Artificial dens should be as close as possible to the destroyed or disturbed fox den.

2) The location should have a high likelihood of kit fox visitation.

3) Den entrances should be oriented to avoid flooding.

4) The den complex should have reduced likelihood of future disturbance, including development, regular maintenance, and human tampering.

Permanent cautionary devices that alert maintenance personnel to the presence of the artificial den may allow construction in regularly maintained areas. If a suitable site is unavailable along the road corridor it may be necessary to arrange for cooperative agreements with adjacent landowners to install artificial dens on their properties. Suitable properties may include railway, canal, or utility corridors, drainage basins, golf courses, parks, and industrial sites. Throughout the site selection and construction process, the suitability for kit fox, the expected longevity, and the impacts on regular maintenance activities should be carefully evaluated.

KIT FOX ROAD CROSSING STRUCTURES

Summary

Vehicle strike is the leading cause of mortality for urbanized kit foxes. The likelihood of strike increases with increasing road width, speed limits, and traffic volume. Strikes often occur at the intersection of roads with linear rights-of-way. Linear rights-of-way include other roads (of all sizes), railroads, canals, utility corridors, golf course crossings, and riparian areas. Kit foxes appear to use linear corridors for movement, potentially accounting for the increase in strikes at these locations.

Major roads and associated features may restrict fox movements and consequently reduce gene flow, dispersal, colonization of habitat patches, and the resilience of fox populations to disturbance. This is especially likely in urban environments where road density, width, and traffic volume are increased and habitat is fragmented and susceptible to change. Maintaining connectivity is identified as a primary recovery action for kit fox in section II.L.6.a. of the Recovery Plan for Upland Species of the San Joaquin Valley, California (U.S. Fish and Wildlife Service 1998).

The construction of fox-specific road crossing structures is a recommended conservation strategy for new high-volume roads, the widening of existing roads, or the rebuilding of existing structures that have the potential to facilitate kit fox road crossings. Potential crossing structures include underpasses, overpasses, and culverts. In the following text we describe crossing structures for urbanized kit foxes and provide criteria for site selection and instructions for building or modifying structures.

Road Crossing Structure Attributes

Little is known about the attributes that make crossing structures appealing to the San Joaquin kit fox. Clevenger (2005) conducted a comprehensive literature review on the subject, but his conclusions suffered from a lack of data specific to kit fox. To fill this gap, Cypher et al. (Interagency Agreement No. 43A0068) have initiated a 2005-2006 study for California Department of Transportation to evaluate non-engineered crossing structures along 4-lane highways within the range of the San Joaquin kit fox and the ecologically similar desert kit fox of the Mojave eco-region. While these data will be useful when they become available, they will have limited applicability to kit fox crossing structures in urban environments.

Urban habitats are highly fragmented, and urban kit foxes develop habitual travel behaviors, often utilizing linear corridors for movement through the complex of human polygonal and linear development. In contrast, the Cypher et al. 2005-2006 study will examine crossing structures on roads that transect native habitat. There is no evidence that kit foxes in natural lands concentrate road crossings at specific features, such as drainage culverts, bridges, or road intersections when medians, fencing, or other impediments are absent.

In a recent study of the effects of two-lane highways on San Joaquin kit fox in natural lands (LoKern), Cypher et al (Interagency Agreement No. 06A0814, 55004872) found no evidence of fox avoidance of highways or of favored crossing locations. It should be noted, however, that traffic volumes on the highways in the LoKern study (approximately 8500 vehicles per day) were similar to volumes found on local roads in the city of Bakersfield (this study). Neither highways at LoKern nor local roads at Bakersfield significantly contributed to kit fox mortality. In other words, there may be little benefit to utilizing crossing structures or other habitual crossing locations when there is little risk of strike.

The following recommendations are based on knowledge of kit fox behavior, movements, territory use, and locations of mortality. We have combined these data with general recommendations on structure design and site selection for similar species. Ideally, crossing structures in urban environments shall be institutionally linked with long-term monitoring programs and clear criteria for determining efficacy.

On the most basic level a crossing structure should satisfy two conditions. First, it should reduce mortality for the target species. Because vehicle strike is the primary cause of death for kit foxes in urban lands, and strikes occur disproportionately on major roads at identifiable geographic features (i.e., intersections with linear rights-of-way), we conclude that crossing structures have a high probability of reducing mortality. Consequently crossing structures are an appropriate and necessary mitigation for urban road projects.

Second, crossing structures should increase habitat connectivity. This is a more difficult condition to evaluate. As noted, urban habitats are highly fragmented. To the extent that roads, and especially high-volume roads, contribute to fragmentation, we conclude that successful crossing structures will increase connectivity. As demonstrated (this study), kit foxes have seasonally influenced behaviors and susceptibility to vehicle strike. During the month of December, male kit foxes increase scent marking frequency (an indicator of territory defense) and movements in search of mating opportunities. Not surprising, there is an increase in vehicle strike for male kit foxes during this period of instability in social dynamics. Furthermore, kit fox juveniles disperse during summer months, sometimes several miles from the maternal range, again encountering many roads. Finally, urban kit foxes are displaced by new development and other human activities, resulting in range instability and dispersal to new territories. It is not known, however, whether the presence and types of roads in the urban environment influence the direction and length of movements and dispersal.

We take a hierarchical approach, from landscape to individual behavior, in describing requirements of fox-specific crossing structures. Criteria include: 1) road type; 2) kit fox presence and adjacent habitat suitability; 3) presence of natural crossing locations; 4) embankments, walls, or fencing that funnel individuals toward the crossing zone; and 5) passage design that meets kit fox behavioral requirements. We stress that these criteria are generated with expert opinion and data from ongoing observational studies of urban foxes. Hypothesis driven experiments will be necessary to evaluate the relative importance of these variables.

Criterion 1: Road type

We examined the distribution of fox-vehicle collisions on four types of urban roads - highway, arterial, collector, and local. Of these, kit foxes disproportionately died on arterial roads. Arterial roads typically were wider and had higher posted speed limits and traffic volumes than collector and local roads. Foxes also died on collector roads in Bakersfield from 1985-2004. In some cases, collector roads had similar traffic volumes and widths to arterial roads. Highways, which had the highest traffic volumes and speed limits, weren't a marked source of fox mortality during this study. The absence of fox-vehicle collision on highways can be explained by a barrier effect –animals that do not attempt to cross, will not be struck. Dispersal of individuals between habitat fragments, however, is an essential function of kit fox populations (U.S. Fish and Wildlife Service 1998) and a reduction in dispersal due to roads has been shown to strongly impact the demographics and extinction probability of small populations (Jaeger and Fahrig 2004). Therefore it is likely that highways posed a significant road effect (if not direct mortality) on urbanized foxes. Lastly, there was little evidence for an association between local roads and fox-vehicle collision or altered kit fox movements.

Based on these findings, we recommend that crossing structures be considered on all highway, arterial, and collector roads. We do not recommend crossing structures as a protection or compensation measure for local roads.

Criterion 2: Kit fox presence and adjacent habitat suitability

Presence of kit foxes may be evaluated by spotlighting, surveillance or track stations, surveying for scat, tracks, and dens, or interviewing citizenry. Presence/absence data, however, may be fallible to some degree. Kit foxes may be absent not because the site is unsuitable, but because of localized extirpation. In fact, fox populations throughout the species' range undergo cycles of extirpation and recolonization, known as metapopulation dynamics (U.S. Fish and Wildlife Service 1998). Metapopulation dynamics influence kit fox demographics and extinction probability, and increase in strength with increasing fragmentation. Furthermore, it has been shown that with growing isolation of habitat fragments, it is less likely that fragments will be recolonized in the event of local extinction. Nowhere is kit fox habitat more fragmented and more frequently altered than in urban environments. Therefore, it is likely that at any given time a subset of suitable habitat in urban environments will be unoccupied by kit fox.

A conservative alternative to presence/absence surveys is to concentrate crossing mitigation at locations that have suitable adjacent habitats. As a general rule urban kit foxes occupy industrial and commercial lands, parks, golf courses, and schools. Within these lands, occupancy appears linked to the extent of contiguous habitat, the quantity of undeveloped or lightly developed lots, the presence of drainage basins (favored den sites), and the presence of linear features that provide den building and movement opportunities such as canals, utility corridors, railroads, and riparian areas. Kit foxes do not typically occupy residential zones unless a golf course or other large open space is present (in which case occupancy is highly likely).

Criterion 3: Areas of increased road crossing

Clevenger (2005) reports that animal use of a crossing structure is linked to placement near natural crossing points. This assessment is supported by crossing studies (e.g., Foster and Humphrey 1995, Yanes 1995). Urban kit foxes more often are killed in vehicle strikes at the intersection of major roads with linear rights-of-way including other roads (of all types), canals, railroads, utility corridors, and riparian areas (this study). The concentration of mortalities at these intersections increases the likelihood of successful mitigation. First it narrows the selection of sites for crossing structures to easily identifiable landscape features. Second, it decreases the need to inhibit crossing at other locations. Third, intersections with linear rights-of-way often have pre-existing crossing structures. For example, a bridge over a canal or river may only require a design modification to be suitable for kit fox. When implemented early in the planning process these modifications may have little additional cost.

Because of the concentration of road crossings and vehicle mortalities at linear rights-of-way, we recommend that mitigation efforts prioritize these locations. For practical reasons, it will not be possible to install crossing structures at most road-road intersections. Instead, we recommend placing highest priority on installing or modifying structures at intersections of roads with highways, railroads, canals, rivers, or utility corridors and other locations where an underpass, overpass, or culvert is required.

Criterion 4: Embankments, walls, and fences

Another important predictor of use of crossing structures and decrease in vehicle strikes is the construction of manmade barriers that funnel animals toward the passageway (e.g., Haas 2000, Clevenger 2005, Mata et al. 2005). Barriers may include embankments, walls, and fences.

Embankments appear to discourage road crossing. Cypher et al. (in prep.) observed regular use by kit foxes of a railway underpass on a raised portion of highway 99 in Bakersfield (Figure 20a). The embankment was approximately eight meters tall and the underpass span was approximately 50 meters wide. Radio-tagged foxes were never known to climb the embankment to travel across the highway surface. Kit foxes constructed dens in the earthen slopes within the underpass and even whelped and reared young at the site for multiple seasons (Figure 20b). Embankments on raised highways may fragment the landscape in the absence of underpasses or other crossing opportunities. Crossing structures should always be considered when building or modifying raised roadways.

Most urban roads are at grade with the surrounding environment. Cement walls may border highways, arterial, and collector roads, but this is typical only of residential areas, which may not be suitable for kit fox. Other roads are bordered by vegetation, low walls, and metal or wood fencing, all of which may be permeable to kit foxes. Small, skilled at digging, and agile, the kit fox is adept at passing through barriers designed for humans or other large mammals.

We recommend the installation of walls at potential crossing sites that encourage use of the passage and discourage crossing the road above grade. Studies on other species suggest that barriers are more effective when they are shaped as a funnel that directs animals toward the structure. It also is recommended that there be a method of exit for animals that get onto the roadway within the barrier zone. The complexity of urban environments makes meeting these recommendations difficult. Nevertheless, barriers are an integral part of successful crossing structures and should be implemented with all crossing projects.

We make the following specific recommendations. Barriers should be approximately 1.5 meters in height and of a solid material, such as cement block, that discourages climbing. Walls should be impermeable to kit foxes that approach from adjacent habitat, but permeable to foxes that are on the roadway. One method to achieve one-way permeability is to install a dirt embankment next to the wall on the side nearest the road that allows a fox to run to the top of the wall from roadside (Figure 21a-b). The wall should remain 1.5 meters above grade on the side that borders habitat to prevent entrance to the roadway. Based on behavioral observations of radio-collared kit foxes and location of kit fox mortalities (this study), barriers should lead directly from the passage and run parallel to the road for a distance of at least 50 meters. In some cases, barriers will best be implemented as part of and in addition to existing natural or manmade features, including embankments, walls, and buildings. Finally, landscaping is recommended between the barrier and roadside (i.e., on the embankment). Urban kit foxes are known to use landscaping for cover while traveling along arterial roadways that are bordered by cement block walls (C. Bjurlin, pers. obs.).

Criterion 5: Behaviorally suitable passage design

We have identified four characteristics that affect behavioral suitability of crossing structures for kit foxes. First, a clear line of sight should be maintained through the passage for the entire breadth of the roadway, with the exit visible from the entrance. Second, approach to the entrances should be level or gently sloped and free from vegetation or obstacles. Third, the passage should be minimally one meter square, with passage dimensions proportional to the roadway (i.e., as road width increases, passage width and height increases). Fourth, one escape den (see above) should be installed within the passage and one escape den installed on the approach to each entrance to give kit foxes protection from predators. In the following text, we profile existing structures to illustrate the aforementioned criteria. We provide recommended modifications where appropriate.

Profiled Crossing Structures

Seven Oaks Golf Course underpass

The Seven Oaks Golf Course in Bakersfield, CA was bisected by Buena Vista road, a four-lane, divided arterial road (Criterion 1). The road segment of interest (980 m) was bounded to the north by intersection with Ming Avenue and to the south by intersection with Chamber Blvd. Traffic volumes were estimated in 2002 at 13,750 vehicles per day (vpd). To maintain connectivity for golfers, an underpass structure was installed. This underpass met nearly all of the criteria for a successful crossing structure. The golf course was occupied by kit foxes and extended on both sides of the passage (Figure 22, Criterion 2). The greens narrowed where they approached the crossing site, creating a natural transverse point (Criterion 3). Two-meter high walls bordered the road (Criterion 4). The passage was greater than two meters square and had flanged and unobstructed entrances (Figure 22b-c, Criterion 5). One confirmed vehicle strike occurred at the site after construction of the barrier wall (Figure 22a). There were gates in the walls at a maintenance yard directly southeast of the passage and at a road access point to the southwest of the passage. A kit fox may have used one of these gates to gain access to the roadway.

Analysis - This design was suitable for locations with pedestrian or bicycle routes, utility corridors, golf courses, or other linear rights-of-way that are not associated with water transport. It would be improved by the installation of escape dens and the modification of the nearby gates to prevent kit foxes from entering the roadway.

Truxtun Extension horse culvert

Truxtun Extension was a 4-lane, divided collector road in Bakersfield, CA (Criterion 1). Traffic volumes in 2002 were estimated at 35,000 vpd. The road segment of interest (5.3 km) occured between the intersection with Wible Road to the east and Coffee Road to the west. The segment was bordered to the north by the Kern River and to the south by a canal and mixed residential and commercial zones. Kit foxes occupied the surrounding lands. Radio-tagged animals repeatedly crossed the road and five confirmed vehicle strikes occurred along the road segment (this study). An underpass culvert was built 270 m east of the junction with Coffee Road. The passage location had suitable habitat to the north (Criterion 2). A pedestrian trail connected the passage to a canal on the southern side of the roadway (Figure 23a-b, Criterion 3). There was a chain link fence that may have impeded access to the road on the southern side, but it was broken by a pedestrian trail 15 m to the west of the southern entrance. The northern entrance had a 20-m chain link fence directly over the culvert (Figure 23c). The road was easily accessible from the north along the remainder of the segment. The culvert was approximately 2.5 meters in diameter with an earthen bottom that was seasonally flooded (Figure 23d, Criterion 5). On one occasion a kit fox was seen running north across the road directly over the crossing structure.

Analysis – This was a suitable passage at an appropriate location that required fencing and escape dens to become fully operational.

Coffee Road bicycle path underpass

Coffee Road was a six-lane, divided, arterial road in Bakersfield, CA (Criterion 1). Traffic volumes in 2002 were estimated at 45,100 vpd. The road segment of interest (1600 m) was bounded to the north by intersection with Brimhall Road and to the south by intersection with Stockdale Highway. Surrounding lands were a mixture of commercial and undeveloped properties and were suitable for kit fox (Figure 24a, Criterion 2). Several canals and the Kern River corridor intersected the road. A bridge that spaned the Kern River also provided passage for a bicycle path on the southern embankment. The river corridor, proximity to road and canal intersections, and presence of a bicycle path made the passage a natural crossing point (Criterion 3). The west side of Coffee Road was bounded by chain link fence, but the east side had open access to the roadway (Figure 24b-c, Criterion 4). The passage was greater than 3m in height and width, and free from obstruction (Figure 24d, Criterion 5). Five confirmed vehicle strikes occurred on the road segment, including one that was 60 m south of the passage (Figure 24a & d).

Analysis – This was a suitable passage under a road with high traffic volume that required fencing and escape dens to become fully functional.

Highway 58 canal bridge

Highway 58 was a four-lane, divided roadway (Criterion 1). The road segment (2200 m) was bounded to the east by intersection with Landco Drive and to the west by intersection with Patton Way. Traffic volumes in 2004 were estimated at 47,000 vpd. Surrounding lands were a mixture of commercial, industrial, and undeveloped properties. A canal and arterial road (Fruitvale Ave) formed a six-way intersection with Highway 58. Kit foxes and their habitat were abundant along the road segment (Figure 25a, Criterion 2). The confluence of canal, arterial road, and highway made it a natural kit fox crossing location (Criterion 3). Chain link fence occured sporadically along the canal, but gaps in the fence and at gates allowed foxes to gain access to the roadway. The road was not walled or fenced. This underpass complex was composed of two separate bridges, one on Fruitvale Ave, the other on Highway 58. The Fruitvale Ave. bridge was impassable at the time photos were taken. The canal was transporting water and there was no embankment along its margin beneath the bridge (Figure 25b). In contrast, the Highway 58 bridge remained passable while transporting water. There were dirt embankments on both margins of the canal beneath the bridge, along with unobstructed entrance and exit locations (Figure 25c-d, Criterion 5). No fox-vehicle collisions were recorded at the location, but kit foxes frequently crossed the road during a telemetry study (Figure 25a). A radio-tagged kit fox was repeatedly tracked to the canal and twice tracked to the canal underpass when there was no water present.

Analysis - The confluence of multiple linear rights-of-way along with presence of kit foxes and frequent road crossings made this an appropriate location for a crossing structure. The fencing at the site was insufficient for keeping foxes off the roadway. When transporting water, one of the bridges did not accommodate fox movement beneath the roadway. This location would require extensive modification to be fully functional.

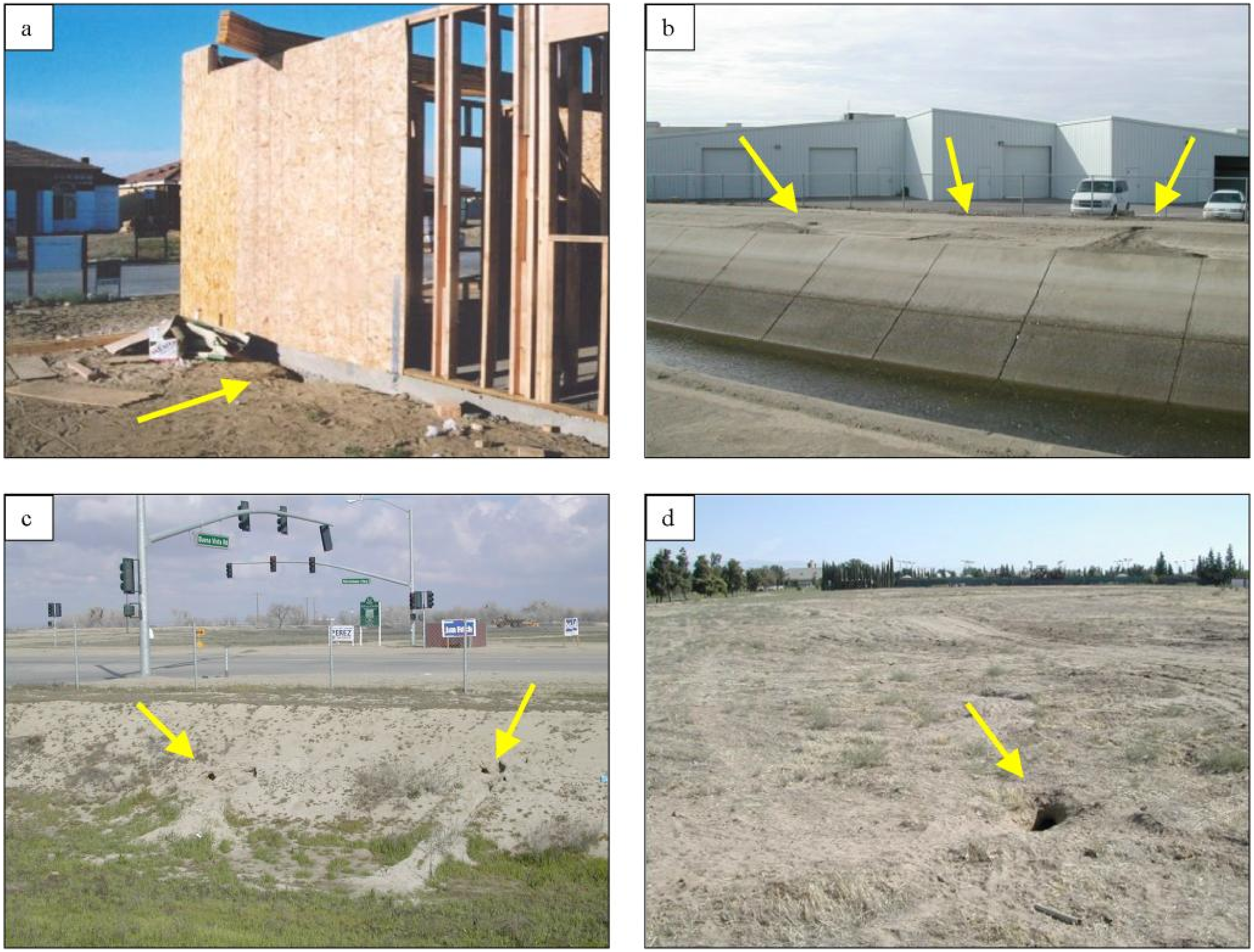

Figure 14. Earthen kit fox dens in urban Bakersfield, CA. a) Single entrance den under building foundation. b) Natal den complex on canal bank. c) Multi-entrance den in drainage basin bordering intersection of two arterial roads. d) Single entrance den in vacant lot.

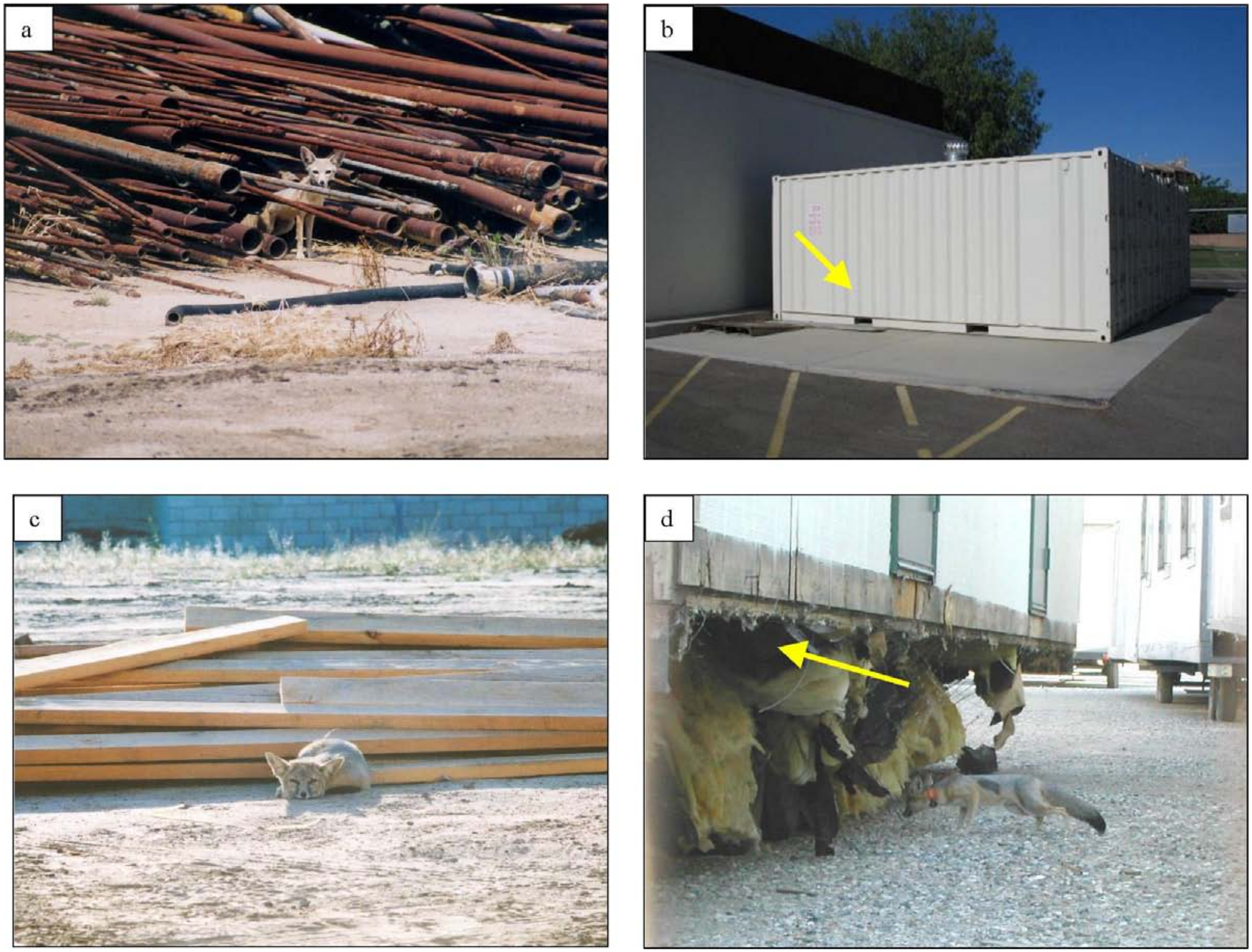

Figure 15. Non-earthen den locations for kit foxes in Bakersfield, CA. a) Fox emerging from stacked pipe. b) Narrow entrances to a kit fox den under a storage container. c) Fox resting beside stacked lumber at a construction site. d) Fox returning to a den within a modular housing unit.

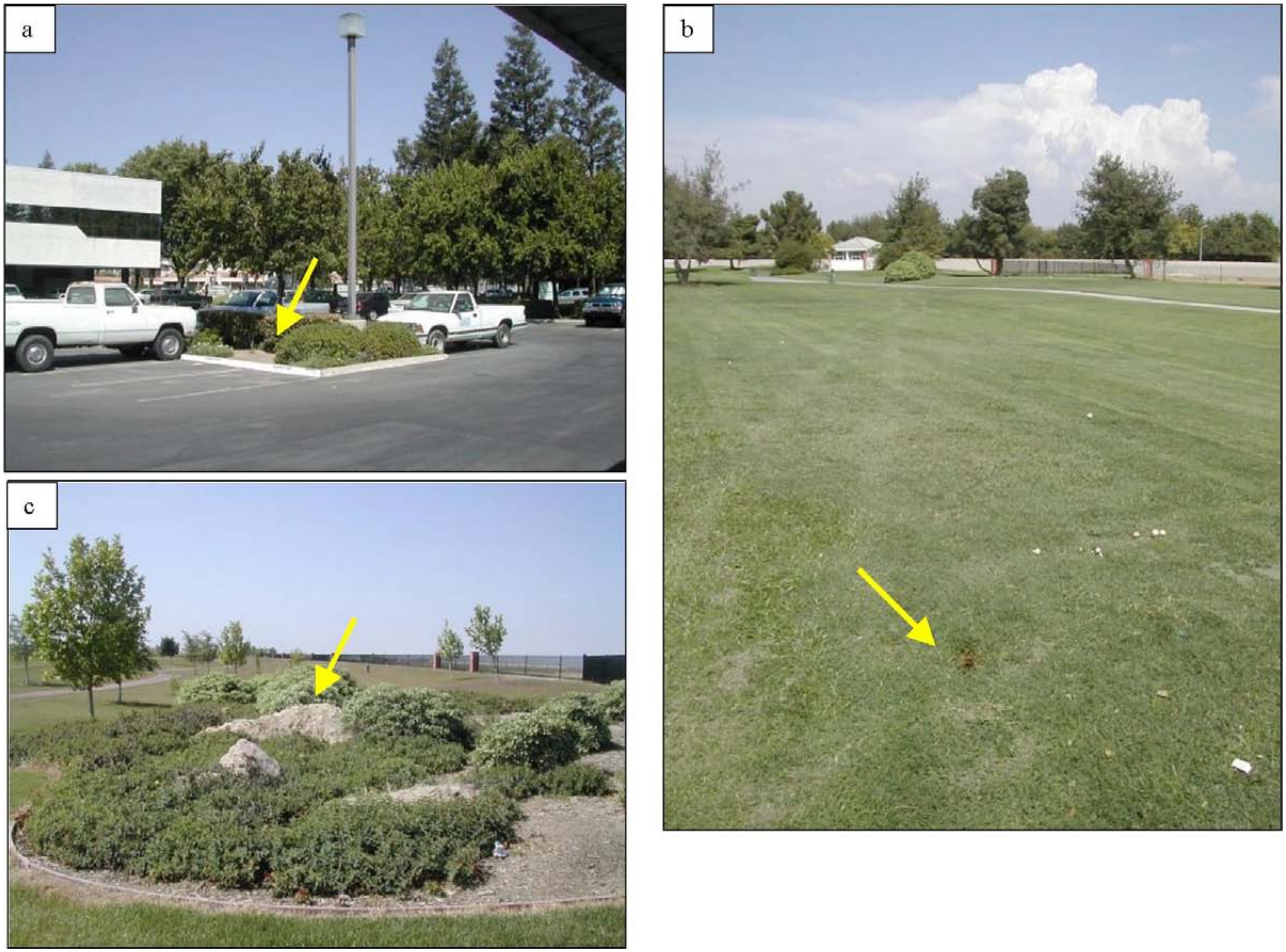

Figure 16. Camouflaged earthen kit fox dens in urban Bakersfield, CA. a) Entrance to den in landscaping at parking lot. b) Thatch covered den entrance in a golf course fairway. c) Dirt mound from den in shrub-island at park.

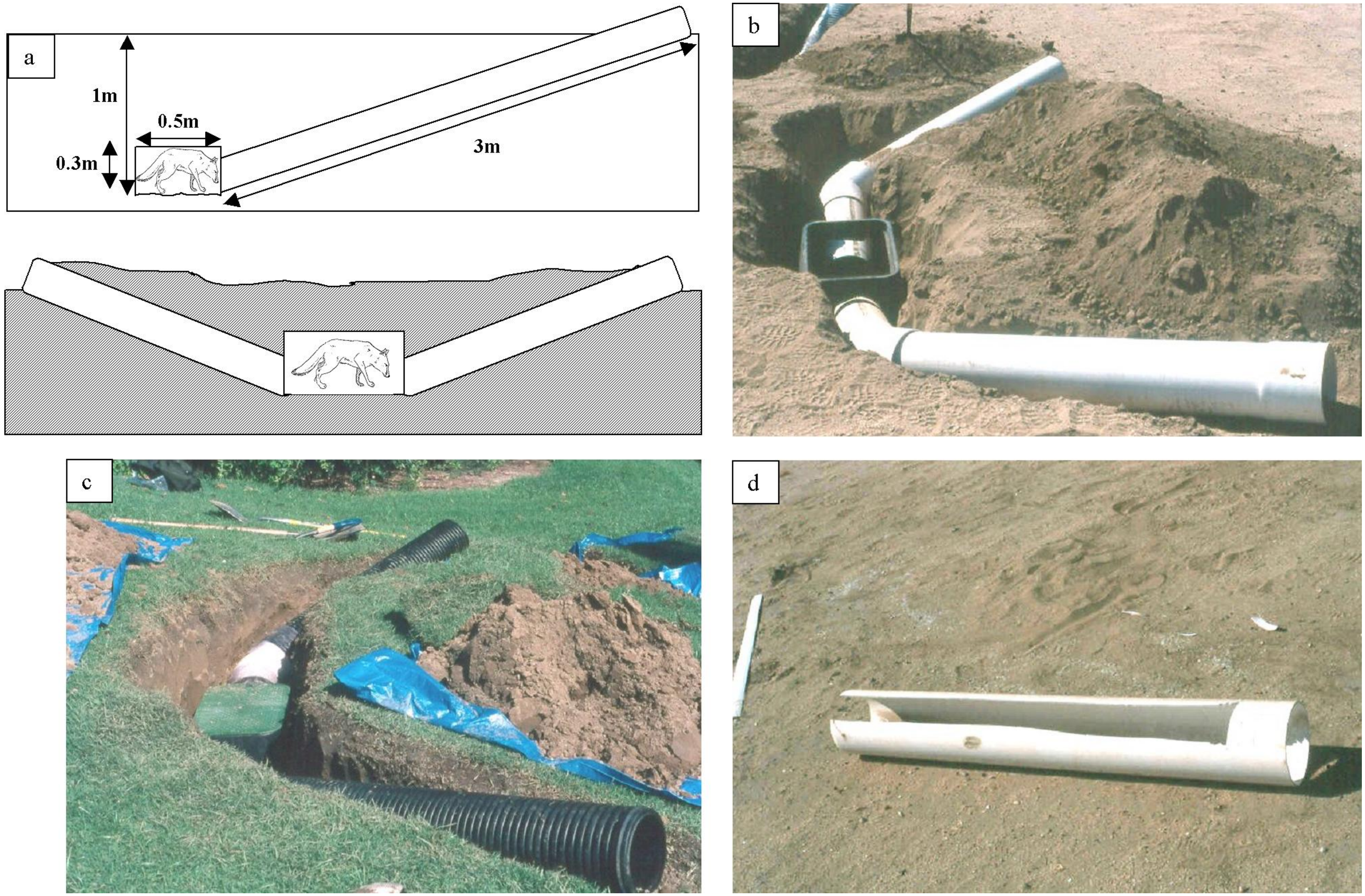

Figure 17. Artificial subterranean dens for San Joaquin kit fox at Bakersfield, CA. a) Artificial den schematic. b) PVC two-entrance chamber den under construction. c) High-density polyethylene two-entrance den. d) PVC tunnel with floor removed longitudinally.

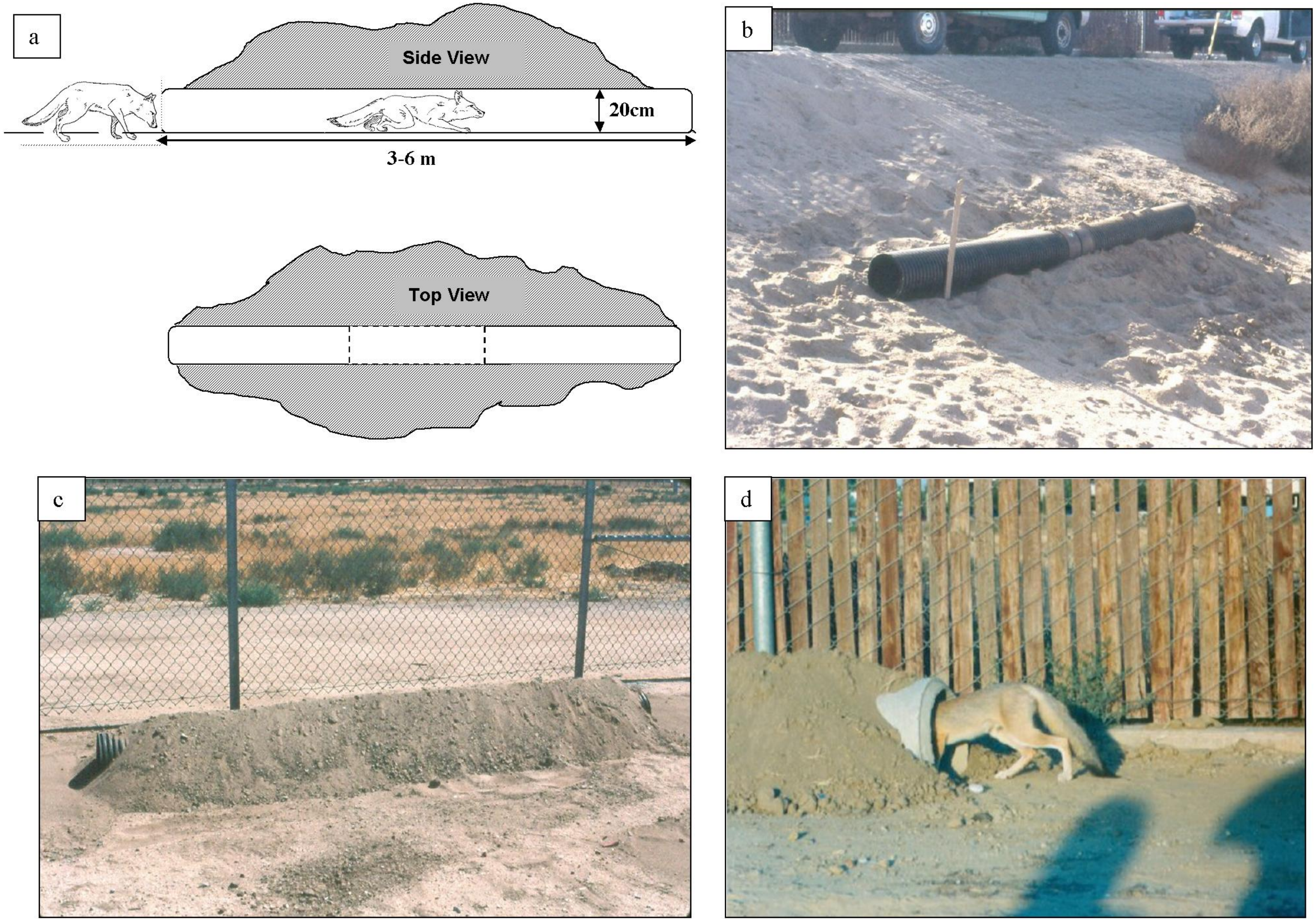

Figure 18. Artificial escape dens for San Joaquin kit fox at Bakersfield, CA. a) Escape den schematic. b) High-density polyethylene escape den under construction. c) Completed den. d) Kit fox entering escape den.

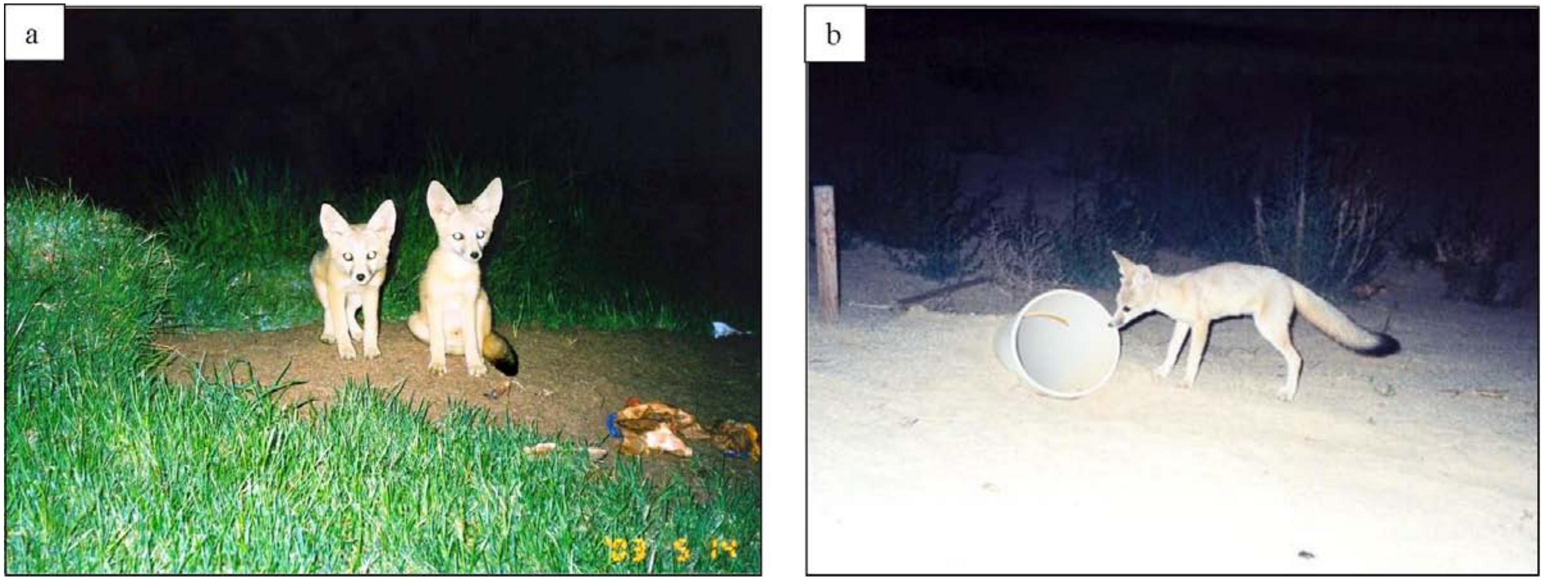

Figure 19. Kit fox pups at artificial subterranean dens at a golf course (a) and drainage basin (b) in Bakersfield, CA.

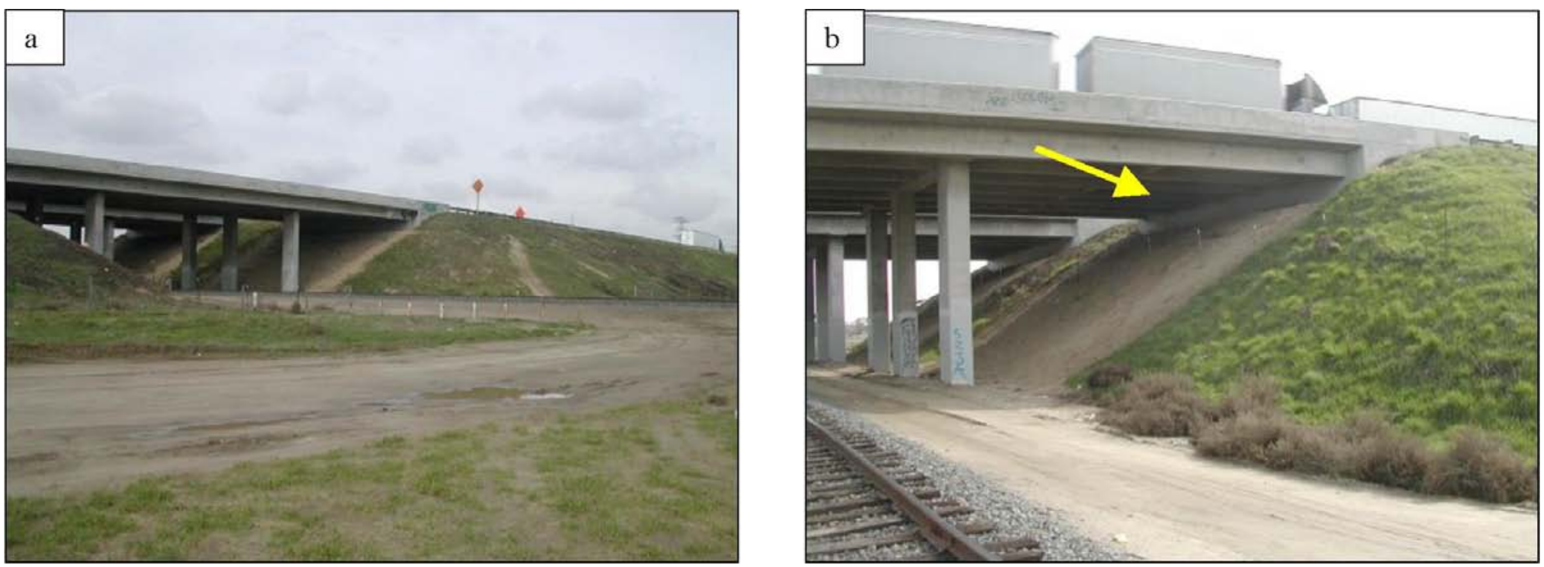

Figure 20. Railroad underpass on highway 99 in Bakersfield, CA. a) Habitat view. b) Kit fox natal den at the top of the underpass embankment.

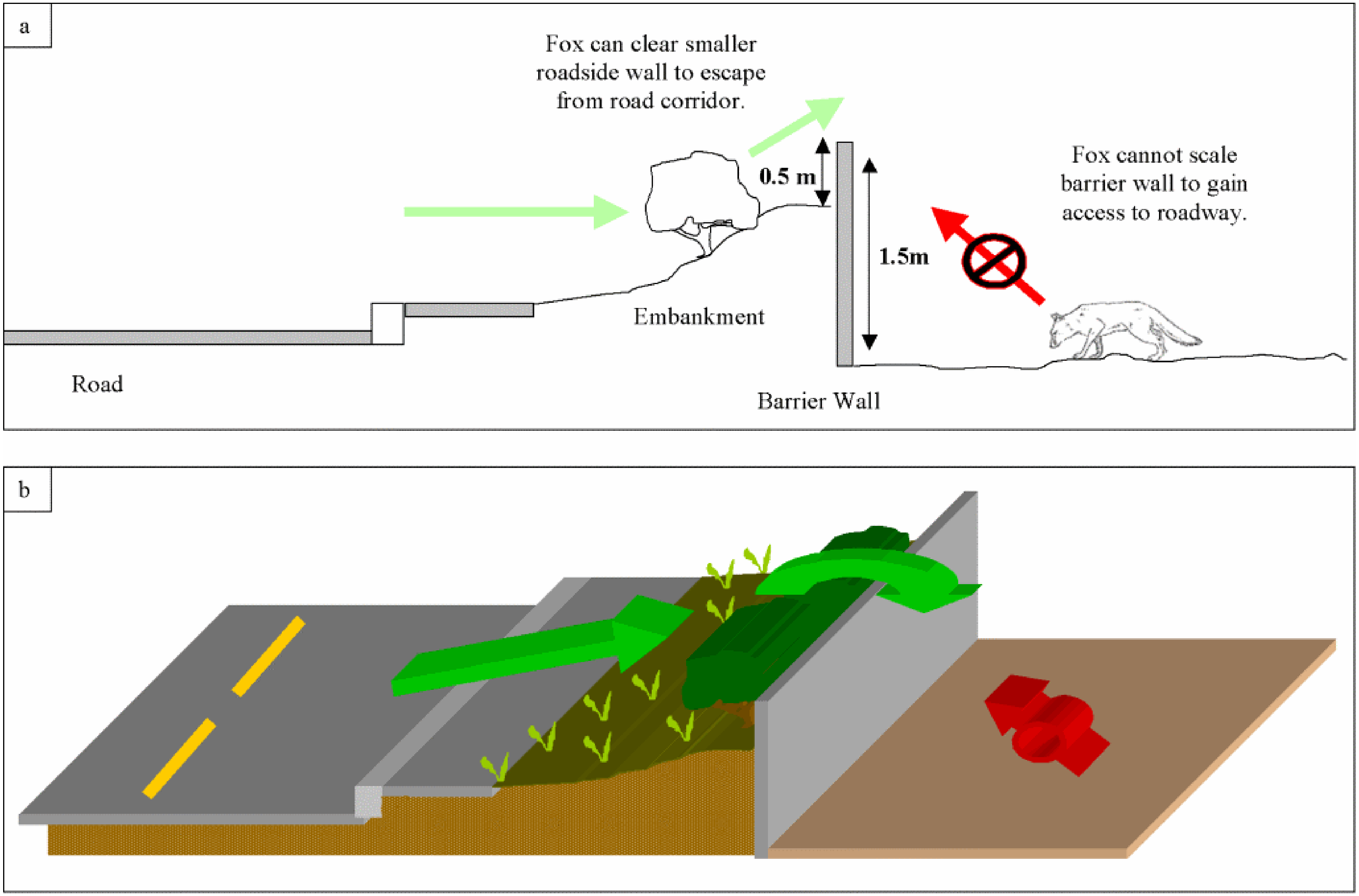

Figure 21. Barrier wall to encourage use of road crossing structures for the San Joaquin kit fox in urban environments. The roadside embankment allows foxes that are trapped on the roadway to clear the barrier wall. a) Cross-section view. B. Three-dimensional rendering.

Figure 22. Buena Vista Road golf cart crossing structure, Bakersfield, CA. a) Aerial view of roadkill and radio-tagged kit fox locations at crossing structure. b) Habitat view from east entrance of crossing structure. c) Approach view to east entrance. d) Passage interior.

Figure 23. Truxtun Extension horse culvert, Bakersfield, CA. a) Aerial view of radio-tagged kit fox locations at horse culvert. b) View from pedestrian trail at south culvert entrance (canal in background). c) North culvert entrance. Yellow line depicts extent of fencing on north side of road. d) Culvert interior.

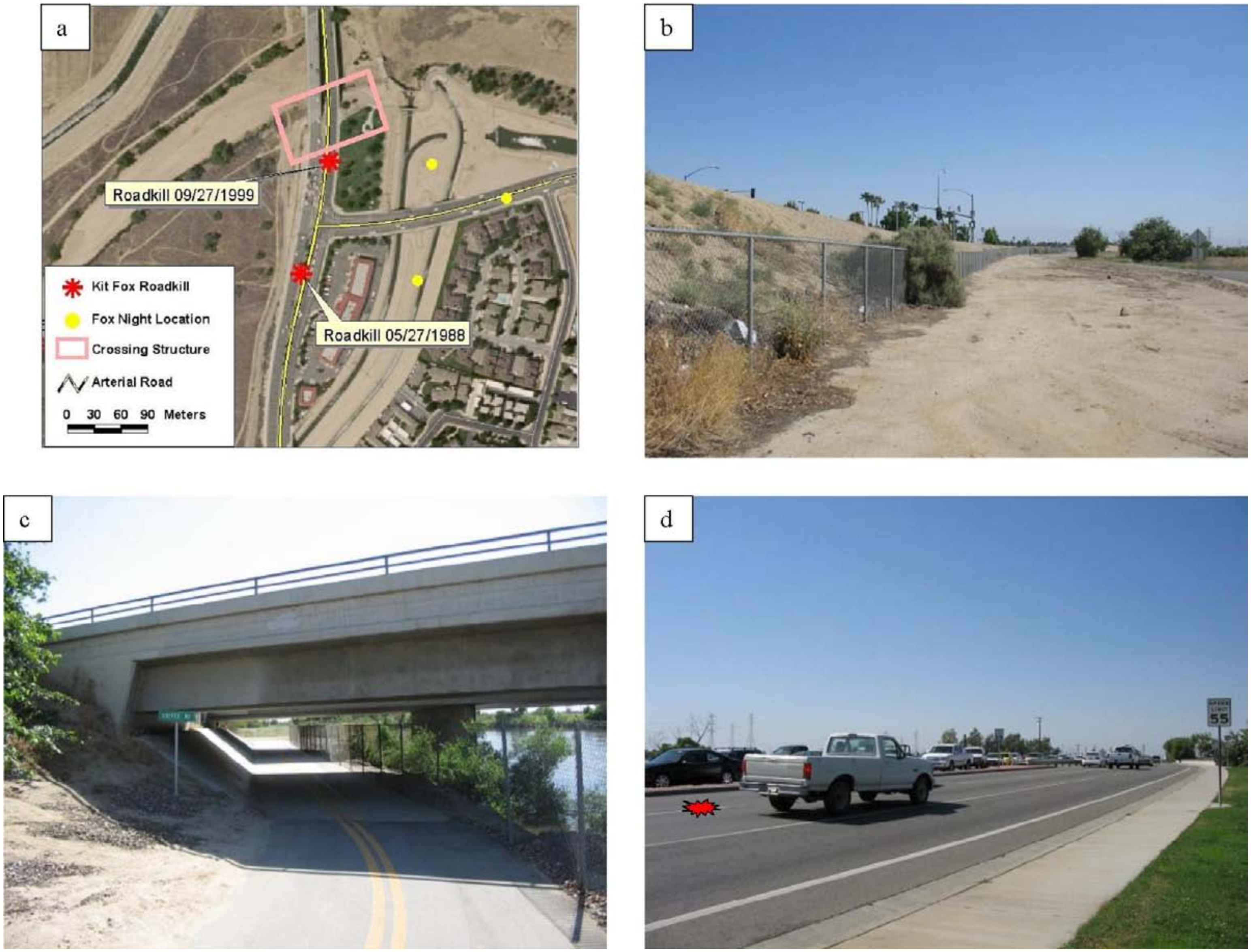

Figure 24. Coffee Road overpass at Kern River bicycle trail, Bakersfield, CA. a) Aerial view of kit fox roadkill and radio-tagged night locations at crossing structure. b) Habitat view from west entrance. c) East entrance to bicycle path on southern embankment of Kern River. d) View of roadway from East with location of kit fox roadkill in red. No fences prevent fox access to roadway on eastern side.

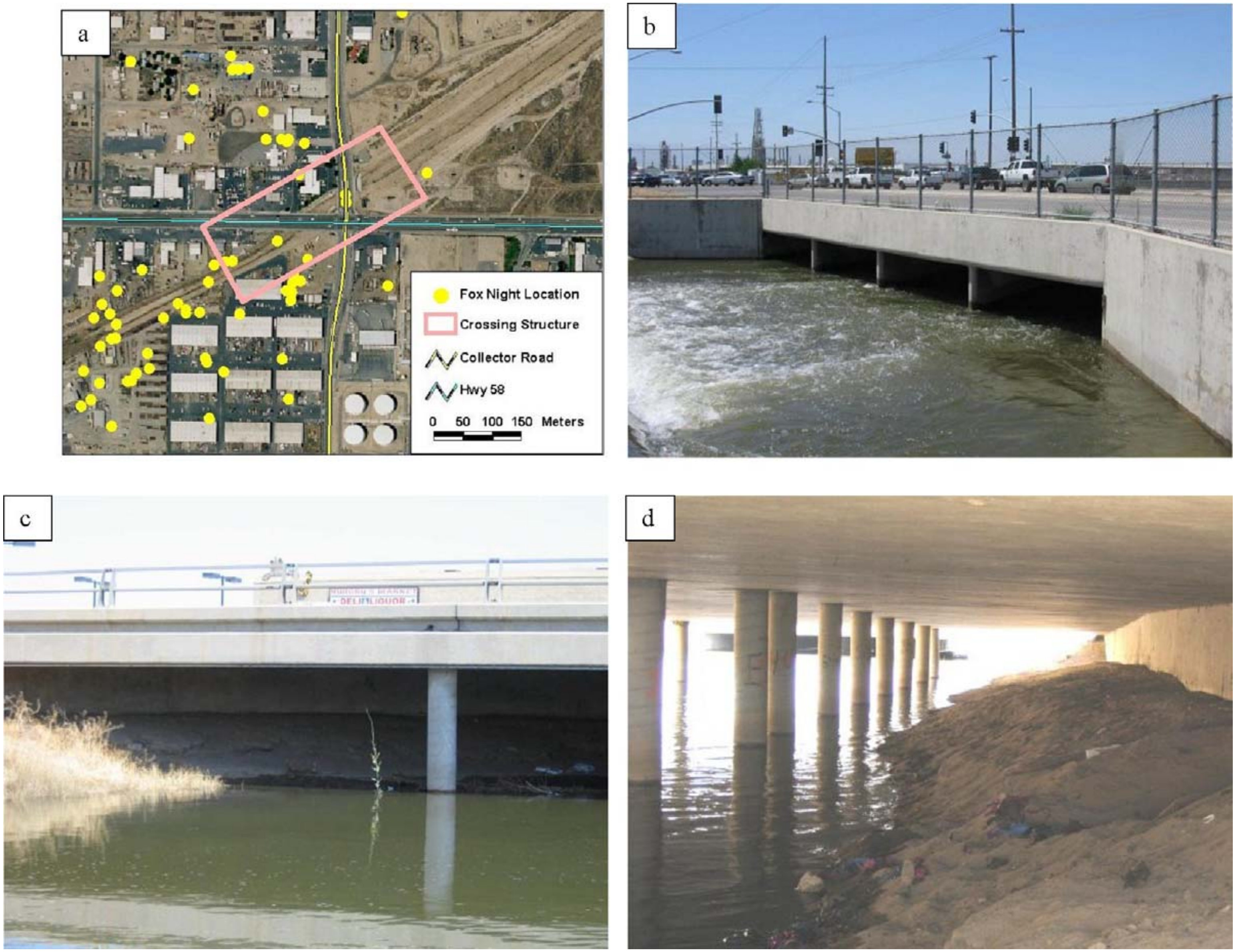

Figure 25. Highway 58/Fruitvale Avenue canal bridge, Bakersfield, CA. a) Aerial view of radio-tagged kit fox night locations at crossing structure. b) East entrance to Fruitvale Bridge obstructed by water. c) South entrance to highway 58 bridge. d) Dirt embankment under Highway 58 Bridge.

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